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DEVELOPMENT OF A MALAYSIAN OCEAN WAVE DATABASE AND MODELS FOR ENGINEERING PURPOSES

(PEMBANGUNAN PANGKALAN DATA OMBAK LAUT DI MALAYSIA DAN MODEL BAGI KEGUNAAN KEJURUTERAAN)

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FAKULTI KEJURUTERAAN MEKANIKAL
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TAJUK PROJEK : **DEVELOPMENT OF A MALAYSIAN OCEAN WAVE DATABASE AND MODELS FOR ENGINEERING PURPOSES**

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ABSTRACT

Correct wave data is a very important input to predict the performances of the marine vehicles and structures at preliminary design stages particularly regarding safety, effectiveness and comfort of passengers and crews. Presently, available wave data in Malaysian seas are based on visual observations from ships, oil platforms and limited wave buoys whose accuracy, reliability and comprehensiveness are often questioned. This study presents an effort to derive a more reliable and comprehensive wave database for Malaysian sea areas using satellite altimetry. Significant wave height, wind speed and sigma0 data is extracted from oceanographic satellite TOPEX/Poseidon for selected area. Results are presented in the form of probability distribution functions and compared to data from Global Wave Statistics (GWS), Malaysian Meteorological Service (MMS), Petronas Research Scientific Services (PRSS) and United State National Data Buoy Center (NDBC). This project has shown that the data provided by TOPEX/Poseidon satellite can be used to derive wave periods and the results indicate that the Hwang Method was the best approach to derive wave period for Malaysian ocean data

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ABSTRAK

Data bacaan ombak yang tepat adalah input yang paling penting untuk menjangka prestasi kenderaan di air and struktur marin pada tahap awal bagi reka bentuk dengan mengambil kira keselamatan, kecekapan dan keselesaan penumpang dan pekerja kapal. Pada masa ini, data ombak yang terdapat di Malaysia adalah berasaskan kepada penilaian mata kasar terhadap ketinggian ombak yang dilakukan daripada kapal, pelantar minyak dan boya ombak yang terhad di mana ketepatan, kebolehkepercayaan dan penyeluruhannya selalu di ragui. Kajian ini menunjukkan usaha untuk membangunkan satu pangkalan data yang lebih dipercayai keupayaannya dan lebih menyeluruh dengan menggunakan satelit altimeter. Ketinggian ombak yang signifikan, kelajuan angin dan nilai sigma0 diekstrak daripada satelit oseanografi TOPEX/Poseidon untuk beberapa kawasan yang terpilih. Keputusannya akan dipamerkan dalam bentuk Fungsi Taburan Kebarangkalian dan kemudian dibandingkan dengan data daripada Statistik Ombak Dunia (GWS), Perkhidmatan Kaji Cuaca (MMS), Pusat Khidmat Penyelidikan dan Saintifik Petronas (PRSS) dan Pusat Data Boya Kebangsaan Amerika Syarikat. Projek ini menunjukkan data yang diperolehi daripada Satelit TOPEX/Poseidon boleh digunakan untuk menerbitkan nilai tempoh ombak dan keputusan menunjukkan yang pendekatan Hwang adalah yang terbaik bagi data laut Malaysia.

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LIST OF ABBREVIATIONS AND SYMBOLS

BMT - British Maritime Technology
CEOS - Committee on Earth Observation Satellite
CNES - Centre Nationale d'Etudes Spatial
CODAR - Coastal Oceans Dynamics Application
ECMWF - European Centre for Medium Range Weather Forecasts
Envisat RA2 - Environmental Satellite Radar Altimetry 2
ERS - European Remote Sensing
ESA - European Space Agency
Geosat - Geodatic Satellite
GFO - Geosat Follow-on
GWS - Global Wave Statistic
H - Wave height
H.F. - High Frequency
Hs - Significant wave height
Hv - Visual wave height
JPL - Jet Propulsion Laboratory
JWA - Japan Weather Association
MGDR - Merged Geophysical Data Record (MGDR)
MMS - Malaysian Meteorological Services
NASA - National Aeronautic and Space Agency
NCEP - National Centers for Environmental Prediction
NDBC - National Data Buoy Centre
NESDIS - National Environmental Satellite, Data and Environment Service
NOAA - National Oceanographic and Atmospheric Administration
ODAP - Oceanographic Data Acquisition Project
OSCR - Ocean Surface Current Radar
P.P.I - Plan Position Indicator

R - Range between satellite and ocean surface

R.M.S - Root Mean Square

S - Satellite orbit

SAR - Synthetic Aperture Radar

Seasat - Sea Satellite

SGOWM - Spectral Global Ocean Wave Model

SSH - Sea surface height

SWH - Significant wave height

T - Wave period

Tz - Zero-crossing wave period

T/P - TOPEX/Poseidon

U - Altimeter windspeed

WAM - Wave Model

WRB - Wave Rider Buoy

WWA - World Wave Atlas

η^2 - Surface elevation

σ_s - Shape of return pulse

σ_0 - Satellite backscatter

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CHAPTER 1

INTRODUCTION

1.1 Background

Ships are built for the purpose of carrying men, material or weapon upon the sea. In order to accomplish its mission, ship must posses several basic characteristics. It must float in a stable upright position, move with sufficient speed, be able to manoeuvre at sea and in restricted waters, and be strong enough to withstand the rigors of heavy weather and wave impact. To design a ship with these features, naval architects must have an understanding of ship dynamics.

With a simple knowledge of hydrostatics a naval architect can produce a ship that will float upright in calm waters. However, ships rarely sail in calm waters. Waves, which are the main source of ship motions in a seaway, affect the performance of a ship considerably and the success of a ship design depends ultimately on its performance in a seaway.

The mission effectiveness of the ship is severely limited if the vessel cannot perform its mission when the sea is rough. This may be due to increased risk to the safety and survivability of the ship, increased demands on powering, or the severity of the motion-induced accelerations, which prevent the ship's crew, equipment and systems from functioning effectively. More often then not, we end up with ships and boats that fail to perform in rough weather condition.

Since the end of the 1950's new analytical methods were developed to predict the response from definition of the wetted surface of the hull and some simple measure of mass distribution. Throughout this performance assessment process, a good and reliable wave data is required. For example, Hoffman and Fitzgerald (1978) emphasized the importance of the simulating operation of crane vessel in realistic waves. Their earlier work shown that errors up to 100% in magnitude of motion may occur arising from the use of inadequate wave data. Data is required regarding the probability of occurrence of wave heights and period in Malaysian waters. This data are presently available based on publications by periods in Marine Meteorology and Oceanography, Malaysian Meteorological Service, example MMS (1996). Also, sometimes data published by BMT (1986) is used. Although there is some problem in accuracy of data based on voluntary reporting, for time being we have to rely on these for probability of occurrence of wave heights and periods.

Since the available wave data for Malaysian ocean are not reliable and comprehensive, new effort to collect wave data must be made. Ocean wave measurement from satellite combined with global wave and atmospheric numerical models are dramatically changing our way of obtaining ocean wave data for engineering purposes. Satellite observations are now at the point of providing reliable global long-term wave statistics. Thus, the aim of this project is to develop Malaysian ocean wave database using satellite in the mission to provide the reliable wave data for Malaysia.

The satellite altimeter uses microwave radar pulse that is sent from orbiting satellite, bounces off the sea surface and returns to the orbiting spacecraft to measure the wave height of sea at a certain location and time. Radio pulse from a satellite altimeter reflects from the wave crest, later from the wave troughs. The reflection stretches the altimeter pulse in time, and the stretching in measured to calculate wave height. The travel time of this pulse is then recorded. The significant wave height is derived from the stand up characteristic of a pulse waveform reflected from the sea surface, crests and troughs on that occasion. The wave data measured by one satellite called TOPEX/Poseidon is available free online given by Jet Propulsion Laboratory (JPL). By verifying the accuracy of the satellite altimeter data, continuous measurement of the wave data of Malaysian ocean can be done at much effective and inexpensive way.

1.2 Objective of the Study

To derive Malaysian ocean waves data using satellite altimetry and present it in a form suitable for engineering purposes.

1.3 Scopes of the Study

This study involves the use of satellite data, processing it using certain techniques and presenting in formats useful for engineering purpose. The study is limited by the following boundaries:

i. The study will only involve TOPEX/Poseidon satellite.
ii. Only wave data from the satellite and relevant associated data will be analysed.
iii. The case study will involve a portion of sea areas; however the method will be applicable to others.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter is giving an overview of the requirement of wave data, the wave data source and currently available wave data collection.

2.2 Wave in Marine Engineering

Knowledge of ocean waves is essential for any activity connected with the seas. The largest forces on ships, as well as on offshore rigs and coastal defences, generally come from surface waves, which can cause delay, damage and destruction. For example, offshore structures have been severely damaged by large waves and have to be regularly repaired against fatigue damage. Millions of pounds of damage have been inflicted upon breakwaters in recent years from the combined effect of waves and surges in sea level (Carter et al., 1989).

To provide efficient advice for these activities not only significant wave height (SWH) but also measurements of the mean wave length and the mean wave direction are necessary. These integral wave parameters are available from a few stations and from ships measuring on opportunity. Certainly, more valuable is the knowledge of the entire wave spectrum, which describes the frequency-direction distribution of the wave energy density.

2.2.1 Coastal Engineering

Waves, generated primarily by the wind, propagate from the ocean to the shoreline across the continental shelves. These waves undergo many processes before they dissipate in the surf zone; refraction, diffraction, shoaling, and breaking. The energy and momentum associated with the waves arriving at the surf zone used to create longshore and cross-shore currents. Wave not only damage breakwaters, but also move the sand comprising beaches and deposit them somewhere else. Taken over long periods for this sand transported away from the site than toward it, this becomes the ‘long-shore drift’, which is an important geological phenomenon. Beside that waves can also be generated by submarine earth quake, volcanic eruption and tides.

The ongoing rise in the sea level due to the glacial melting since the last ice age and now perhaps accelerated by the Greenhouse Effect creates a pervasive mechanism for shoreline retreat. Tidal inlets, connecting bays or lagoons to the ocean, also contribute to the shoreline retreat by capturing beach sand into ebb and flood shoals. The processes of coastal erosion are very complex, involving three dimensional flow fields created by the breaking waves, unsteady turbulent sediment transport in both the water column and on the bottom, and a moving shoreline (Holman, 1995). Further offshore the role of the waves seems to be more that of mobilizing the bed material, which is then moved by tidal and other currents. The other side of this coin, many researches are being conducted worldwide to develop predictive models of this erosion process.

Numerous devices have been devised to stop the erosion process. These can be divided into two basic types which is the hard and soft structures. Hard structures have been the traditional tool of the coastal engineers. These include groins (structures oriented perpendicular to the shoreline to slow the transport of sand along a shoreline), jetties (placed at inlets to keep sand from the navigational channel), breakwaters (to reduce wave action in harbours), and sea walls (to prevent the erosion of the upland). The soft structures are those that are more natural. The primary example is beach nourishment, which is the placement of sand on an eroding beach. Nourishment is a short-term measure, as it does not fix the cause of the erosion; however, it is the only method that involves adding sand to the coastal system. Mangrove is also one of the natural coastal protections and believed to have reduced the damage caused by the recent Tsunami in December 2004.

2.2.2 Seakeeping

Seakeeping calculations are important in assessing the performance of a floating structure. It is particularly the operability aspect, and critical for small crafts such as patrol boats. Unlike most large ships, which use the oceans only as a highway for commerce, patrol vessels perform their primary mission of security patrol at sea; often performing these complex maneuvers in hostile conditions. The effectiveness and efficiency of these tasks depend very much upon the seakeeping capability of the vessels. Boats that behave poorly in bad weather not only endanger the life of the crew, but also may have a less effective delivery capability. Moreover, weather downtime will be increased, limiting the number of effective surveillance and patrol.

As the descriptive tool for seakeeping events, one way considered being the most useful for direct calculation of many valuable statistics is uses the energy spectrum. The pioneering work of Denis and Pierson (1953) on the application of superposition and spectral analysis techniques to seakeeping studies revolutionized seakeeping analytical studies. The energy spectrum is simply a presentation of the squared amplitudes of the frequency component of the sample records. This type of presentation, which indicates an estimate of the true spectrum, permits the treatment of ship behavior in the frequency domain so that ship performance can be related to the frequency response characteristics of the ship. Resultant responses of the ship can be estimated from the sum of responses of the ship to a train of individual regular waves of known frequencies (Omar Yaakob et al., 2003).

The wave incidents on the vessel are assumed to be long-crested. For such waves, the way in which the energy of the sea distributed at various encounter frequencies is given by the sea spectrum $S\zeta\ (\omega e)$. By the principle of linear superposition, the sea spectrum can be related to the motion spectrum through the transfer function or response amplitude operator, RAO. If the motion RAO per unit wave amplitude or the transfer function at various encounter frequencies are designated $H\ (\omega e)$, the spectral response of the selected response is $Sr\ (\omega e)$ then the particular seaway is given by:

$$Sr(\omega e) = S\zeta(\omega e) \times \left| H(\omega e) \right|^2 \qquad (2.1)$$

The above method is normally used to predict motion responses of floating vessels. The sea spectra in this case are either actual sea-spectra measured at sea or idealized theoretical approximation such as Bretschneider, Pierson-Moskowitz or ITTC spectral formulations (Bhattacharya, 1978).

Equation (2.1) is also useful in full-scale experimental studies. If the time series of the waves heights incident on the vessel and the associated vessel motion response can be measured, $S\zeta(\omega e)$, $Sr(\omega e)$ and hence $H(\omega e)$ can be calculated. This method is indeed useful, because it will enable us to derive the transfer function and hence RAO from the response spectrum of the vessel under test using

$$H(\omega e) = \sqrt{}\ Sr(\omega e)/\ S\zeta(\omega e) \qquad (2.2)$$

The transfer functions obtained in this manner can be used for comparison with RAOs from theoretical studies. Also, they can be used to estimating the response of the vessel in other seaways for which spectrum can be defined.

In absence of actual sea spectra, theoretical sea spectra are used. There are various theoretical representations of the sea spectra. Standard textbooks on waves mechanics or seakeeping refer to these spectra representation with various names such ITTC, ISSC, Breitschneider, Pierson-Moskowitz, and JONSWAP etc., see for example Bhattacharya (1978). Most of these belong to a general class of spectra referred to as the gamma-spectra. The gamma-spectrum has the standard form:

$$S(\omega) = D\omega^{-1} \exp^{-B\omega\text{-}n} \qquad (2.3)$$

The four parameters D, B, *l* and *n* control the shape of the spectra. The parameter *l* determines asymptotic behavior of the high frequency tail of the spectrum. Parameter B is scale parameter of the frequency linked to the peak frequency, Ω through:

$$B = 1/n\, \Omega^{n} \qquad (2.4)$$

Parameter D determines the overall level of the spectral density and does thus indicate the general severity of the sea state. D is normally considered a universal constant $D=\alpha g^2$ where α is Philips constant equal to 0.0081. The frequently used gamma spectrum is Pierson-Moskowitz spectrum. It has the form:

$$S(\omega)=0.0081g^2/\omega^5 \exp^{-5/4(\omega/\Omega)\text{-}4} \qquad (2.5)$$

i.e. the values of *l* and *n* are 5 and 4 respectively.

For not fully developed sea, the spectrum has distinct peaks and to take these into account, peak-enhanced Pierson-Moskowitz spectrum is proposed and renamed as JONSWAP spectrum:

$$S(\omega)=0.0081g^2/\omega^5 \exp^{-5/4(\omega/\Omega)\text{-}4} + \exp^{-1(\omega-\Omega)^2/2(\sigma\omega)^2} \ln\gamma \,\} \qquad (2.6)$$

In this case γ is the peak enhancement factor, the effect of which is to increase the peak of the spectrum.

Despite the preponderance in the use of theoretical sea spectra, it is more recommended to use actual sea spectra. If that is not possible, sea spectra more tailored to the local eave conditions should be used. Hoffman and Fitzgerald (1978) emphasized the importance of simulating the operation of crane vessel in realistic waves. Their earlier work has shown that errors up to 100% in magnitude of motion may occur arising from the use of inadequate wave data. Soares and Trovao (1992) investigated sensitivity of seakeeping prediction to spectral models and concluded that short-term responses are sensitive to the type of spectral model used while for long-term predictions only Pierson-Moskowitz model could be used.

Thus, it is important to have an accurate knowledge on the characteristics of the ocean waves when estimating the seakeeping performance of ships at sea (Ogawa et al., 1997). The wave used for the design ship is long-term data in all condition. Therefore, there is a need to establish the method of continuous wave data collection (Sakuno et al., 2003).

2.2.3 Offshore Engineering

Waves are generally the most important environmental factor producing forces on offshore structures. The design of offshore structures used for oil and gas present problems, due to environmental hazards from wind and current forces and the weight of the structure. In traditional design techniques the structure is first designed to withstand the most severe conditions which it is likely to meet in 50 or 100 years. Thus, as well as an estimate of extreme wave conditions; the statistics of all waves throughout the year have to be specified. The system for reliability techniques has been developed. In these, the probability distributions of the loads are calculated and compared with the ability of the structure to withstand these loads, also on a probability basis: that is, taking account of variable factors such as the yield stress of the steel and the strength of the welds. The risk of failure can then be estimated and kept to a sufficiently low value.

In relation to the development of offshore oil and gas production at the offshore sea, there was a big push to gain enough knowledge to ensure the safety of the offshore structures in relation to the environmental forces. Oil price rises caused by high oil demand in the 1970s has prompted offshore development throughout the world in order to be self sufficient. However, there is plenty left to do as more sophisticated methods of design are introduced by engineers. An example is that designers now wish to take advantage of the low probability that the adverse extreme environmental factors will all occur simultaneously, but oceanographers cannot yet provide them with the necessary information on joint probabilities of occurrence (Tucker, 1991).

2.2.4 Wave Power

The power is very variable, of course, so that there must be alternative methods of generation available. This means that the cost of the power has to compete with the cost of the fuel saved and not with the total generating costs. While solar radiation and winds are distributed over the planet's entire surface, wave energy is concentrated along coastlines, which total about 336,000 km in length. At a global renewable rate of 10^{12} to 10^{13} watts, the average wave energy flux worldwide is of the order of several to a few tens of kilowatts per meter of shoreline (kW/m). Thus the energy density of ocean waves is at least an order of magnitude greater than the natural processes that generate them.

The energy present in ocean waves have been recognized since dawn of civilization mostly through its destructive actions. But effort to harness this source of energy has driven inventors to come up with inventive and novel ideas and devices to convert energy present in the ocean waves to a more useful form of energy. The first reported patent for a wave energy device was filed in 1799 in Paris, by the Girards, father and son. Since then more than one thousand patents have been filed in various countries with only few ideals that show promises in its ability to capture and convert wave energy effectively. During 1970s, an increased interest on wave energy conversion was seen due to the dramatic increase in oil prices especially in Europe. The greatest efforts were concentrated in United Kingdom, Norway and Japan. Efforts by others European nations and countries such as Sweden, Portugal, Denmark, India, China, Australia and United States also contributed to the advancement of wave energy conversion techniques and devices (Pin, 2005).

After a series of research into the possibilities, it soon became apparent that the available wave data were inadequate both to assess the resource and for design of the wave energy converters. Directional information is needed, and the techniques for routine directional measurement were only just being developed. It was therefore necessary to develop techniques to provide a long term measurement of the wave and this opportunity seen in the remote sensing technique. What the designers required was a set of directional wave spectra representative of the long-term wave climate, which they could use in model basins to test the overall performance of their devices. Some clever and ingenious devices to harness the power were designed and tested at model scales. In the end, none seemed capable of development into economic systems where the competition was large mainland fossil-fuelled generating stations. However, where the competition is relatively small diesel generators, which is typical of the situation on islands, then the economics look more promising, and developments of this type are under way at the present time (Tucker, 1991).

2.3 Wave Data Sources

Based on the variety of the requirement for wave data, there are also various categories of wave data available such as instrumental measurement, visual observations, wave forecasting and remote sensed to fulfil this purposes. However, there are advantages and disadvantages among them according to the nature and origin of data (see Appendix A). For example, whether the visual observation is the most useful data for wave data requirement, the probability of wave height of the ship report is thought to be smaller than other data sources because ships tend to try to avoid the storm seas. On the other hand, buoy measurement is considered to be one of the best sources of information since it measures wave mechanically, however it has a disadvantage of limited number of deployments for vast area of the oceans (Ogawa et al., 1997). Although there are many types of sensor working under remote sensing method and it seem all of them had accuracy and derivation algorithm problem, but the satellite altimeter data seems to be one of those fields where optimist feel that the promise is great. The information below briefly explain about this wave data available in sort of the principles and how its work.

2.3.1 Instrumentals Measurement

Wave instrumentals measurement or direct observation was the most accurate way to measure the wave height concerning the area of each particular study. But this method needs a highest cost, expose to the vandalism and unfortunately scarce limitary point data in the fields of wide areas. For example, Draper et al. (1965, 1967, and 1970) presented statistics from measurements performed with a Tucker wavemeter at some Ocean Weather Stations (OWS), during a period of 3-4 years, but the total number of measurements of each station corresponds roughly to only one year of complete data. This is too short length of time to allow the statistical confidence necessary to long-term predictions (Gonzalez et al., 1991). Thus this measured wave data can only be used to calibrate the others measurement. There are four main categories of instruments to measuring the wave, which are known as wave staff, sub-surface sensor, buoys and shipborne systems (See Appendix B).

Wave staffs are also known as fixed instruments measuring waves are used when a structure is available to mount them on or, rarely when it is economic to build special structure. The output can be recorded on site, telemeter to shore, or sent along a cable. One problem, which is often quite serious, is that they need to be mounted well away from any sizeable structural members: 10 diameters away. The examples for this wave staffs are stepped-contact staffs, resistance-wire staffs, capacitance-wire gauges and the Baylor wave gauge.

Generally sub-surface sensors are mounted on or near the seabed and are either self-contained and therefore have to be recovered and replaced at regular intervals, or connected to shore via a cable. A snag with the former is that a malfunction may result in a considerable length of data being lost before it is downloaded. In the case of the latter, the cable route must avoid areas where trawlers operate or ships anchor. The examples for this measuring system are pressure sensors, inverted echo sounders and particle velocity meters.

Apart from remote sensing devices, the only way of satisfying this requirement is to use sensors, which are in buoy or small vessels. There are many offshore buoys deployed in the oceans mainly by meteorological agencies, and it has been found that a wave-recording buoy can gives results, which are not influenced by proximity of a structure. They are considered to be unbiased and the most reliable gathering wave information since they measure waves by mechanical or electronic instruments. Despite with these advantages, the buoy has a reduced area of coverage and the limited availability, which is often due to commercial restrictions (Gonzalez et al., 1991).

A small buoy floating on the sea surface moves up and down with the waves. Its vertical acceleration can be measured, this can be integrated twice to give the vertical displacement. Although the concept is simple, there are a number of problems in its successful implementation. There is really only one device which has overcome the entire problem successfully, and it has become the industry standard for offshore recording. This is the Waverider manufactured by Datawell in the Netherlands (Tucker, 1991).

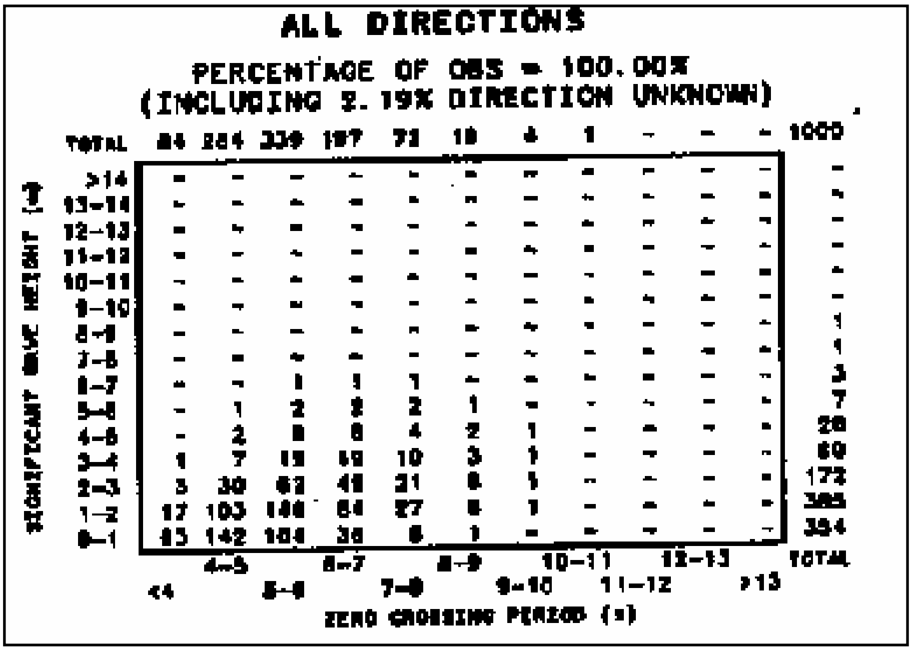
A number of devices have been devised which rely on the attenuation of waves with depth, in effect using the deep still water as a reference. Although some of these have been used successfully for short periods, they have largely fallen into disuse following the successful development of accelerometer buoys. Most buoys telemeter the wave data to a platform or to a shore station, though some also record on board to improve the data return for historical data. Direct radio telemeters can be used for short range. For longer ranges, buoys have been designed which telemeter via satellites. In this case some data compression is required to reduce the number of bits to the capacity of the satellite channel. Gonzalez et al. (1991) describes a system in which a Wave Buoy transmits by radio to a nearby ‘mother’ buoy that is enough to contain adequate battery supplies and which is retransmits the data via GEO/METEOSAT satellite. This has a larger data capacity. The examples for buoys are Pitch-roll-heave buoys, ‘Clover-leaf’ buoys and Particle-following buoys.

The Shipborne Wave Recorder (SBWR) was the first device capable of recording waves on the deep sea during a storm. Although not very accurate by modern standards, its cheapness to run and high data return have led to its extensive use. Mounted symmetrically on each side of whether ship and light vessels. Each contains a vertical accelerometer mounted on a critically damped short period pendulum, and a pressure sensor connected to the sea through a hole in the side of the ship. The accelerometer outputs are integrated twice and added to pressure signals, giving in each case the surface elevation relative to a fixed horizontal plane. These concepts are very simplified of what actually happens in practice. The interaction of the ship and the waves is complex, particularly in relation to the distribution of pressure on the hull, and satisfactory theoretical treatment has not been found. However, some are still in use today. Thus, its existence has made a significant contribution to our understanding of waves.

2.3.2 Visual Observations

There is a huge volume of observations of waves from ships in normal service all over the world, and these are held in data banks of various meteorological offices. A major source of visual wave data is the compilation made by Hogben and Lumb (1967), which cover most of the ship routes to and from Europe. The Pacific Ocean is not so well documented but this can be supplemented with the data from Yamanouchi and Ogawa (1970), which covers that ocean in detail. Another important compilation is due to Walden (1964), containing visual observations performed in the North Atlantic Ocean Weather Stations (OWS), during a period of 10 years.

As the wave statistical data, generally, are often shown in the form of occurrence frequency diagram, correlation table, of significant wave height and average wave period. However, Global Wave Statistics atlas, Hogben et al. (1986) (GWS) (see Figure 2.1) wave data presented in terms of joint probability distribution of significant wave heights and zero-crossing wave period for the global selection of 104 sea areas. The data represent an updated and corrected version of the Hogben and Lumb (1967) data. The observations are divided into subsets for each combination of area, season, and wave direction classification used. In particular, the distribution of the wave periods conditional on the wave height was corrected by an analytical modeling of the joint probability distribution of heights and periods, avoiding use of visual observations. Afterwards, this distribution, together with the marginal distribution of visually observed wave heights, was used to reconstruct the scatter diagram of wave heights and periods by a computer analysis program (Bitner-Gregersen and Cramer, 1994).



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PERCENTAGE OF OBS = 100.00%
(INCLUDING 2.19% DIRECTION UNKNOWN)

SIGNIFICANT WAVE HEIGHT (m)	<4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	>13	TOTAL
>14	-	-	-	-	-	-	-	-	-	-	-	-
13-14	-	-	-	-	-	-	-	-	-	-	-	-
12-13	-	-	-	-	-	-	-	-	-	-	-	-
11-12	-	-	-	-	-	-	-	-	-	-	-	-
10-11	-	-	-	-	-	-	-	-	-	-	-	-
9-10	-	-	-	-	-	-	-	-	-	-	-	-
8-9	-	-	-	-	-	-	-	-	-	-	-	1
7-8	-	-	-	-	-	-	-	-	-	-	-	1
6-7	-	-	1	1	1	-	-	-	-	-	-	3
5-6	-	1	2	2	2	1	-	-	-	-	-	7
4-5	-	2	8	8	4	2	1	-	-	-	-	20
3-4	1	7	15	19	10	3	1	-	-	-	-	60
2-3	3	30	62	41	21	8	1	-	-	-	-	172
1-2	17	103	146	64	27	8	1	-	-	-	-	385
0-1	43	142	104	36	8	1	-	-	-	-	-	354
TOTAL	64	284	339	197	71	18	4	1	-	-	-	1000

ZERO CROSSING PERIOD (s)

Figure 2.1: Joint probability distribution function diagram (scatter diagram) for area 62, (BMT 1986)

The format of its standard scatter diagram is derived by a rounded number of one thousandth (1/1000) for its print out version and accuracy of 0.000001/1000 for its PC version. The wind observations were used to improve the reliability of the wave statistics. Unfortunately, many of the voluntary observing ships do not have anemometer installed but determine the wind speed via visual estimation by relating simultaneous visual estimates of wind strength on the Beaufort scale, wave height and wave direction. These are analysed on both a seasonal and an annual basis (Tilo and Stephan, 2000).

There are the advantages and disadvantages on the visual observation method to derived wave data. According to Soares (1986), it has three important properties of wave data from voluntary observation ships that make it unique. The first and probably most important aspect is that it already incorporates the effects of bad weather avoidance. By avoiding the very large storms due to early meteorological information the probability of failure of ship structures are from high sea states can be much reduced. Because avoidance measures are the result of subjective evaluations of the ship captains, the process is difficult to model analytically. Thus, the use of data from voluntary observation ship appears as the possibility of representing the effect and this makes the data of voluntary observing ships preferable for the analysis of ship structures. However it is inappropriate to the analysis of fixed structures such as platforms. In this case the data from the Ocean Weather Stations is more appropriate. Another advantage of the data from transiting ships is that it is collected along trade routes used by merchant ships, where the need for information is greatest. A third advantage is that the estimates of mean values are likely to have no bias. Because the observations are made in many different ship types and sizes, they show reasons supports the hypothesis of systematic differences between measurements made in different geographical areas. Although the assessment properties of the sea states by visual observations involves a significant degree of estimation variability, but it is possible to collect large samples of data, which may compensate for the variability because it is relatively inexpensive procedure.

On the other hand, because of the visual data usually come from ship reports which is an important part of them are concentrating on the main shipping routs, these data bring up some shortcomings due to observation itself. Firstly, the wave height was reported in adverse climatic conditions tend to be overestimated by the observer and secondly, more ships sail in good weather conditions consequently samples are biased toward lower wave height values. The result is that this sample does not fit accurately of the lognormal model, which is usually appropriate for wave study, when the observations reported as calms are included in the sample (Gonzalez et al., 1991).

The visual observation also shows a large correlation coefficient and variability lower or equal than any of the hindcast techniques. Observations made by voluntary ships and trawlers in the North Sea (Ewing and Hogben, 1966) show the same trend as the comparison between voluntary ships and weather ships (Hogben and Lumb, 1967), i.e. voluntary ships over predicted the amount of low waves and under predicted the amount of larger waves. However, two main reasons have been advanced by Hogben and Lumb (1967) to explain the conclusion that voluntary ships tend to underestimate wave height from weather ship. Firstly, it was the larger size of the voluntary ships which would lead the observers to make the lower estimates. Secondly, voluntary ships can dodge some of the rough while the weather ships are always on station.

Not surprisingly, discrepancy between the Global Wave Statistics (GWS) and instrumental data is observed. For the considered locations, the GWS data both underestimate as well as overestimate significant wave height while the zero-crossing wave period (Tz) mean value is systematically overestimated for low Hs while it is underestimated for large Hs. The opposite effect is observed for the standard deviation of Tz. The marginal empirical cumulative distributions of Tz, indicate also that the GWS data may underestimate the extreme wave periods. However, the instrumental database applied in the study is too limited to draw general conclusion as well as to specify a regression of the instrumental data on the GWS data. The GWS data represent the average conditions for each of the 104 ocean zones, while the instrumental data used in the analysis are representative for specific locations only (Bitner-Gregersen and Cramer, 1994).

Some of the research had also shown that the GWS have a different quality at the different ocean areas. For example, Chen & Thayamballi (1991) had compared the effect of use of the GWS data contra hindcast data in ship response analysis. For some ocean zones the GWS data have led to higher responses and slightly higher fatigue damage. However, that was not the case for other ocean zones. Therefore it was concluded that two sets of wave data were not quite consistent and should be used with care. It is also show by Bitner-Gregersen et al. (1993), which had compared the GWS data with the Wave Rider Bouy (WRB) and Oceanographic Data Acquisition Project (ODAP) buoy wave data, which was accepted as the standard wave measurements for design work at sea. The 20 years extreme values were evaluated based on the GWS data deviated from extremes obtained by use of the instrumental wave buoy data. It was indicated that the GWS data might underestimate the zero-crossing wave period as well as overestimate the significant wave height. It was also indicated that the uncertainty involved in use of the GWS data contra the instrumental data might be larger than the variation in wave induced loads and fatigue damage, between the different ocean areas (Bitner-Gregersen and Cramer, 1994).

The bias of wave period mean value and standard deviation in GWS is smaller for the North Atlantic than for the other locations considered. Comparison of the GWS and instrumental empirical probability densities of Hs and Tz, presented by Andrews et al. (1983), confirms also that accuracy of the North Atlantic GWS data seems to be satisfactory. The North Atlantic area has a high density of traffic, resulting in a larger database for this area, and a better agreement with the instrumental data for this area is therefore also to be expected.

While the quality of individual observations is questionable and the other type of wave data is now available, visual observations of wave height are still the main source of statistical information of waves during the last twenty years, that covers most of the oceans areas for the prediction of extreme wave conditions to be used in the design of ship structures. Generally, when using ship observation, data have to be carefully checked and evaluated (Tilo and Stephan, 2000). The usefulness of these visual observations depends, however, on a proper calibration with the accurate measurements of the wave characteristics. For example, Hogben et al. (1986) compared the GWS marginal distributions for wave height and periods, for which statistics was given, corresponded to be necessary to apply any correction factors, usually used for estimating significant wave heights from visual wave height observations. From the different regression equations available, the one have been recommended by the International Ship Structures Congress are the ones due to Hogben and Lumb (1967):

$$Hs = 2.55 + 0.66\ Hv \tag{2.7}$$

Applying the proposed equations to an observed sea state will under predict the wave height by 7%. This value indicates the magnitude of the uncertainties involved in transforming visually observed wave height in occasional ships to instrumental wave height. It is not too large, being of the same order of magnitude of other uncertainty sources in the calculations of wave loads. However, accuracy of the data is still questioned in the literature (Gonzalez et al., 1991)

2.3.3 Wave Hindcasting

Hindcast wave data could be an alternative to visual wave observation. Compared with data from instrumental measurements, hincast data cover a much wider sea area and do not miss storms because of instrument malfunction. Hindcast techniques use records of wind speed to estimate corresponding wave conditions. This is achieved by modeling the process of generation and propagation of waves by wind (Gonzalez et al., 1991). The hindcast data as a good means of interpolating wave statistics between instrumental sites, they give data over longer periods and also give directional information, which is available from very few instrumental sites. The models described here are basically for deep water of intermediate depths. The final run-up to the coast or over shallow banks is a complicated matter.

This method has been carried out for many years, but the modern development was triggered by Second World War, when in all theatres of war the Allies had to make landings on enemyheld beaches. An ability to predict the wave conditions was vital. Early methods were largely concerned with predicting the wave height and period from the local wind, taking account of the distance over which the wind was blowing its ‘fetch’ and the time for which the wind had been blowing at a more-or-less constant speed its ‘duration’. Such methods are still useful in certain circumstances. As the speed and capacity of computers develop, it became practicable to design models which take account of the propagation of wave energy from one area to another. However, because of the limited power of computers and of the lack of adequate understanding of wave generation processes, the early models had to be rather simplistic in their approach.

The second generation of finite-difference model resulted from a clearer understanding of the energy transfer processes, in particular the third-order processes, but had to simplify the representation of these because of the limitations of computer power at that time. Second-generation models have been in routine use for many years and large data sets have been built up. What usually stored is sometimes known as 'nowcast' data: that is, the estimate of the wave field at the time of calculation taking into account the most recently available wind data. A preferred method to gain long-term wave statistics is to run wave forecasting models on historic wind data a process known as 'hindcasting'. The historical wind information is more reliable then the real-time estimates of wind fields, partly because a considerable quantity of late information can be incorporated. In hindcast model, it is usual to run the model for most severe to run it for a long continuous period (Tucker, 1991).

Increases in computer power and improvements to the algorithms for computing third-order wave-wave interactions have made it possible to develop a 'third generation' model in which the spectrum is developed step-by-step, using the full energy balance equation. Develop in recent year, the hindcasting are prepared using numerical wave models with the hindcast wind as input and using the physics of wave growth, transmission and decay (Carter et al., 1989). This has the advantage of not having to make priori assumptions about the spectral shape, and should therefore give better results in complicated conditions such as hurricanes.

The advantage of hindcast methods is that wind data is more abundant and generally more reliable than visual observations. Some ships are equipped with anemometers that measure the wind speed, with less error than the visual estimations of wave properties (Quayle, 1980). A large hindcast study has been going on for some years to generate a wave data base for the North Atlantic, as reported by Cumming and Bales (1980). Another important program covers the North Sea and denoted by NORSAW (Haring, 1979). Hindcasts exist also for the Mediterranean Sea (Lazanoff et al., 1973).

Recently, wave data collection using hindcast method was generated by Japan Weather Association for global wave database. The database is the simulated wave data (wave height, wave period, wave direction and wind velocity) using JWA3G model, 1985-1999 (15 years). Time and grid intervals are 6 hours and 2.5 degree (about 250 km mesh) (Tilo and Stephan, 2000). Also, there is a Wave Model (WAM) [WAMDI Group (1988)], which was operated routinely at the European Centre for Medium-range Weather Forecasts (ECMWF) (Staabs and Bauer, 1998). Modelled Hs are provided from WAM (cycle 4) with global 3º x 3º grid and with forcing by ECMWF 6-hourly wind fields. The modelled Hs fields are stored every 6 hours. The major improvement of WAM cycle 4 with respect to WAM cycle 3 is the dynamic coupling between the wave-induced stress and the atmospheric stress (Komen et al., 1994).

However, substantial uncertainty can be obtained from calibrations of hindcast methods. On the other hand, the hindcasting methods are not very accurate and considerably improved if the models are initiated and updated with others sources observations of wave height and period (Carter et al., 1989). In the last decade, the performance of wave models has significantly improved, due to improved accuracy in the wind forcing fields, and to the assimilation of altimeter data (total energy of waves). It has been shown that the assimilation of altimeter data in wave model improves the forecast of the Hs (Lefevere et al., 2003). For example, errors in wave modeling using WAM are caused mainly by incorrect wind forcing and less by insufficient resolutions. Since August 16, 1993, Hs from the European Remote Sensing (ERS) altimeter have been assimilated into the WAM model at ECMWF (Staabs and Bauer, 1998).

Nowadays ERS-2 wind/wave altimeter data are assimilated on a daily basis in several meteorological centers. With the launch of ENVISAT and Jason, we should have the unprecedented opportunity of the availability in quasi-real time (within few hours) of data from several altimeters and from SAR, offering an improved coverage. A system able to assimilate all these data should provide higher quality wave field analyses and forecasts (Lefevere et al., 2003). Finally, it is important to note that these major hindcast programs concern ocean areas which are already reasonably well documented by various types of wave data. Therefore they do not fill the gaps of the visual wave data and cannot be considered yet as a real alternative (Soares , 1986).

2.3.4 Remote Sensing in Wave

Remote sensing is one of the indirect observations and it is defined as making measurement by using electromagnetic waves, so that no mechanical disturbance of the sea-surface is caused. This indirect observation is not so sensitive comparing with the direct observation but we can get the data easily and cheaply in wide areas with the same instrument in short time of period. Remote sensing is widely applied to research of the ocean. At present the space-borne radars allow us to realize a global overview of the state upper layer of the ocean surface and to obtain information on its characteristics, such as significant wave height (altimeter), and wind speed (altimeter and scatterometer). This information is necessary for the solution of a broad list of problem in oceanology, meteorology, navigation and ocean safety engineering. Electronic wave scattered by the ocean surface contain the information on its characteristics. A wide range of electromagnetic wavelengths has been successfully used, from infrared pulsed lasers to high frequency (H.F) radio waves travelling horizontally over the sea surface and being reflected back by sea waves of half their wavelength.

There are two classes of remote sensors for waves; direct and indirect sensors. Direct sensors measure directly some relevant parameter of the wave system. The example is the altimeter and Doppler radar. The interpretation of results of sensors is reasonably straightforward. Indirect sensors are the main system, which have interaction via some other physical process, usually by its interaction with wave at or near the Bragg resonant wavelength. This needs a greatly complicated interpretation. Large amounts of effort have been put in these systems, but they are still not very accurate quantitative tools. The example of this type sensor is Synthetic Aperture Radar (SAR), H.F radar and Plan Position Indicator (P.P.I) ground based radar. There are various type of radar based on the position of the sensors transmit the electromagnetic such as Ground-based Radars, Airborne sensors and Satellite-borne sensors.

2.3.4.1 Ground-based Radars

a) Vertical Radar

The first type of Ground-based Radars is the vertical radar. It is the simplest in concept. A transmitter mounted, for example, an offshore platform sends a pulse of radiation vertically downwards in a narrow beam and measures the delay before the echo from the sea surface is received. This delay may be measured digitally or converted to an analogue signal, and it measures of the elevation of the sea surface immediately below the instrument. An infrared laser device developed by Thorn-E.M.I has been successfully deployed at several sites. Dacunha & Angevaare (1988) give the results of a long-term intercomparison of one of these with other wave sensors, showing good agreement. More recently, it was intercompared with many others wave measuring devices by Allender et al. (1989) in the Wadic experiment. Although it occasionally gave short flat sections and was slightly ‘spiky’ near the crests of very large waves in severe storms, these were considered to be minor faults, and it was in fact chosen to provide most of the reference data set used. Microwave radars have also been used for this application.

b) Plan Position Indicator (P.P.I) Radar

P.P.I. radar is also ground base radar. Conventional high-resolution short-range ships radars are suitable for this application, with minor modifications. One complete sweep of the radar is photographed at suitable intervals. The gain is set so that the ‘sea clutter’, that is, the echoes from the sea-surface, is clearly visible. The height of the radar is fairly critical. As the height is raised, so the reflection of signals from distant waves increases, but at too great height the contrast is lost and the image of the wave disappears. A height giving a grazing angle of about 0.5^{o} at extreme range seems to be about right. The precise physical mechanism at work in producing the backscatter pattern are not too clear, though in some cases it seems likely that reflections from the crest are being seen with the wave trough being shadow. Such installations are comparatively cheap and simple. They give the predominant direction of the waves, and this is very useful, in conjunction with a point wave recorder, for coastal engineering problems. Working further offshore in a depth sufficiently great so that changes in the phase velocity of the waves are negligible over the area of a radar image, navigation radar mounted on a ship or other suitable platform can be used with a more sophisticated system of analysis.

If there is a current present (or the ship is drifting), this produces a Doppler shift in the frequencies of the waves. The current can be estimates by measuring this Doppler shift from the temporal transforms. In the presence of noise, this involves estimating the position of the peak of the spectrum. The result from all the spatial harmonics can be averaged to give a better estimate of the current. Having obtained this current, one can go back to the temporal transform and select just the energy at the frequency corresponding to the revised dispersion relationship (that is, taking account of the Doppler shifts). Young et al. (1985) claim that the resulting low-noise spectrum is the same shape as the true surface elevation spectrum of the waves.

c) Microwave Doppler Radar

The third type of the ground base based radar is the Microwave Doppler radar. In concept, these shine a narrow microwave beam to illuminate a small patch of the sea surface, and measure the Doppler shift of the echo due to the very short Bragg-resonant waves being carried back and forth by the surface particle velocity due to the longer waves. If the wave system is considered as the linear superposition of many components, then for each component (in deep water) the particles travel in circular orbits. If all the wave components were travelling towards the radar, then the statistics of the particle velocities seen by the radar would be the same as the statistics of the vertical velocities. When integrated, they would then give a displacement time-history whose spectrum and statistics would be the same as those of a vertical displacement record. Note that this is not true when wave are nonlinear, so such radars cannot be used to measure the shape of extreme waves. However, they do measure the horizontal component of surface particle velocity correctly in nonlinear waves, and this is a very useful measurement.

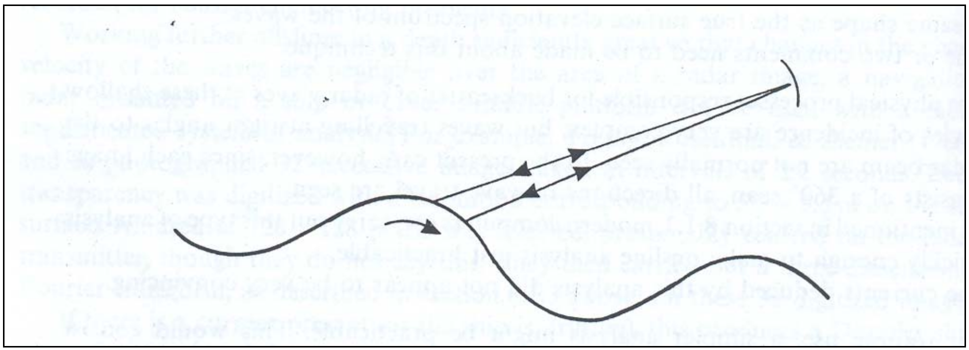


Figure 2.2: A microwave Doppler radar looks at small patch of the sea surface (Tucker, 1991).

d) High Frequency (H.F) Radar

The H.F radar is now established as a powerful tool for measuring the pattern of surface currents over an area out to a range about 30 km, with an accuracy of about ± 3 cm/s in all conditions. Much has been claimed for its potential for measuring directional wave spectra out to ranges of perhaps 150 km, but the development of this still had a rather limited success. Three main practical versions of H.F. radar have been developed. The first was the CODAR (coastal oceans dynamics applications radar) intended for measuring both waves and current, and develop by Barrick and Lipa (1979). The second was the Ocean Surface Current Radar (OSCR) developed by King et al. (1984) specifically for current measurement. The third is longer wavelength H.F. radar developed at the University of Birmingham by Shearman et al., (1987) mainly for wave measurement.

The radars are used are coherent stretched-pulse radars which is continuous transmission radars arranged to illuminate only one approximately rectangular patch of the sea-surface. The backscattered signal is received and its spectrum computed, giving a result as in Figure 2.3. In 1955 D.D. Crombie showed that the radar echo from a patch of the sea-surface contained two main spectral lines, one positively and one negatively Doppler shifted from the transmitter frequency. These lines corresponded to echoes from the Bragg resonant waves travelling towards and away from radar. With no current, the Doppler shifts are equal to the frequency of the Bragg resonant wave, and therefore in the range 0.1 to 0.6 Hz approximately. If a component of the surface current is following towards the radar, it will increase the Doppler shift of the approaching wave and decrease that of the receding wave.

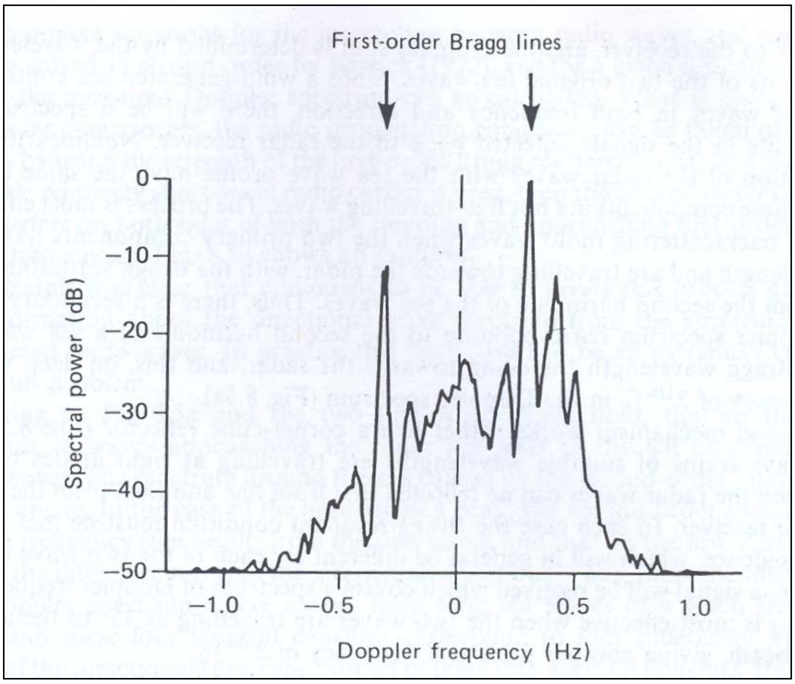


Figure 2.3 : A measured H.F radar backscatter spectrum (Tucker, 1991).

For wave measurement, more complex second-order mechanism of backscatter is therefore used. Hasselman (1971) and Barrick (1972) established this technique as the foundation. Because the hydrodynamic equations are nonlinear, two wave trains of different frequency and direction interact to form two further components of the surface profile with different wavelength and moving in different directions. If the direction of one of these second-order wave trains coincides with the radar look direction and the Bragg resonant condition is met, it will reflect radio energy back to the receiver, then the Doppler shift was determined by the wavelength and directions of the two original sea waves. Since a wind-generated sea contains a wave spectrum of waves in frequency and direction, there will be a spectrum of Doppler shifts in the signals reflected back to the radar receiver. Note that these components are not free-travelling waves. Thus, there is a secondary peak in Doppler spectrum corresponding to the second harmonic of a sea wave of twice the Bragg wavelength travelling towards the radar.

The second mechanism works rather like a corner-cube reflector (See Figure 2.4). If two sea wave trains of suitable wavelengths are travelling at right angles to one another, then the radar waves can be reflected first from one and then from the other back to the receiver. In each case the Bragg resonant condition must be met at the angle of incidence, which will in general be different for each of the two wave trains. Thus, again, a signal will be received which covers a spectrum of Doppler frequencies. The process is most effective when the two waves are travelling at 45^{o} to the axis of radar beam, giving another peak at a frequency of $2^{3/4} f_{B}$. Other small peaks can sometimes be seen corresponding to the third and fourth harmonics, but these are not considered in the analysis.

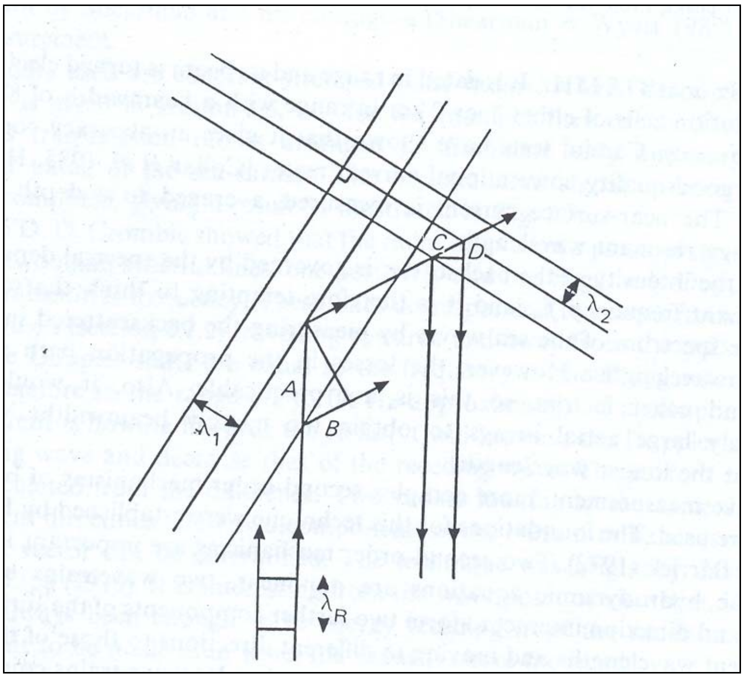


Figure 2.4: How corner-cube reflection works for H.F. radar (Tucker, 1991)

2.3.4.2 Airborne Sensor

a) Radar Altimeter

Many attempts have been made to measure waves by using a narrow-beam vertical radar altimeter mounted in an aircraft flying low over the sea, so that the illuminated patch is small compared to the sea wavelengths of interest. These have all been unsuccessful partly owing to instrumental difficulties, partly to the cost and other problems of flying aircraft, both during development and operationally, but more fundamentally because of the difficultly of interpreting the resulting records. The aircraft is flying faster than the phase velocity of the waves, but there will be some component wavelengths and directions for which the resulting frequency as seen by the aircraft is near zero, and such waves are not measured. It is impossible to keep an aircraft at exactly constant altitude, so that low-frequency noise is also introduced. In practice, this noise has seriously contaminated the results, even when a vertical accelerometer was used to measure the vertical motion of the aircraft and to compensate for it.

b) Surface Countering Radar

Walsh et al. (1985) describe an airborne surface contouring radar which measures the directional spectrum of the waves. This is across-track scanning radar, which contours the sea-surface in 51 cells across the track of the aircraft and in sections of 1024 cells along the track. The resolution is 1.4^{o} across the track and 1^{o} along the track, with 15cm in surface elevation. The aircraft was flown at heights of 200 m and 400 m, giving surface resolution of 3 to 5 m across the track and about 5 m along the track. The system is corrected for the roll of the aircraft, and for the Doppler shifts in the wave spectrum due to the drift and forward speed of the aircraft. Ambiguities are removed by using two directions of flight, but this works only if the wave spectrum at any particular frequency has a single directional lobe. Comparisons of this system with other surface sensors gave very encouraging results. The system seems more suited to one-off experiments than for routine measurements, not only because of the costs of flying an aircraft routinely, but also because it seems unlikely that the aircraft could fly at the low altitude required in the extreme conditions when routine measurements are most important.

c) Radar Ocean Wave Spectrometer (ROWS)

This concept has been implemented from aircraft, but is in principle suitable for satellites. The short-pulse radar is directed at the sea surface at a relatively steep angle of incidence (10^o to 13^o from the vertical for the proposed satellite instrument). The pulse is backscattered from the sea surface, and the time history of the backscattered energy is analysed. The pulse is short enough to resolve the sea wavelengths of interest in the range direction, but the width of the illuminated patch is several wavelengths, thus averaging wave travelling across the range direction and giving directionality. The returns from successive pulses are averaged in range bins fixed relative to the sea surface. The aerial is rotated to look at the sea successively in all directions. It is assumed that the law relating the backscattering cross-section σ_0 to the wave characteristics is known, so that the Fourier transform from each directional look can be related to the directional spectrum in a known way (Tucker, 1991).

2.3.4.3 Satellite Borne Sensors

a) Radar Altimeter

A number of altimeters of the same general type have been flown. Their main application has been to measure the shape of the Earth’s surface, and this has shown some fascinating results. The microwave radar altimeter is conceptually the simplest of the active remote sensing instruments, and, after nearly two decades of spaceborne operation, it has become a well-developed and documented tool. The primary purpose for the development of the spaceborne altimetry was oceanic physics, where altimeters were proposed for the measurement of mean sea level and sea state. In addition to oceanographic applications, the satellite altimeter has proven to be a useful tool for studying the continental ice sheet of Greenland and Antarctica. The satellite altimeter is a nadir-pointing instrument designed to measure the precise time it takes a radiated pulse to travel to the surface and back again. If the orbital position of the satellite is known relative to a reference surface, then the measured time converted to range can be used to derive the elevation of the reflecting surface (See Figure 2.5) (Davis, 1992).

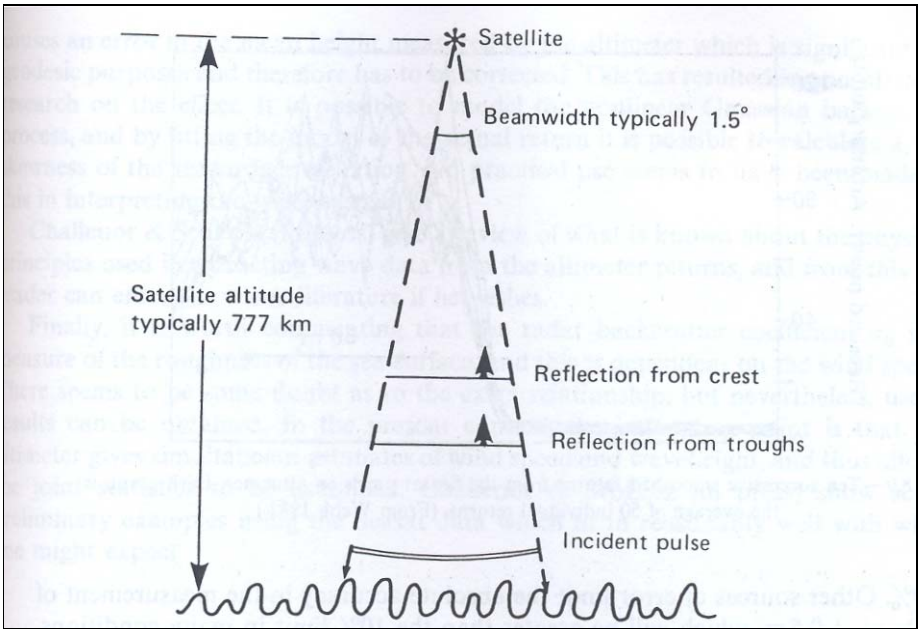


Figure 2.5: The satellite borne precision altimeter used for measuring wave height (Tucker, 1991).

b) Synthetic Aperture Radar

The Synthetic Aperture Radar (SAR) produces an image of the sea surface (See Figure 2.6), and the analysis starts by a 2D spectral analysis of subsets of the image. However, the SAR image spectrum has turned out to be far from the actual wave spectrum and rather complicated post-processing is necessary for extracting quantitative wave information. The core of the methodology is Hasselmann's non-linear ocean-SAR spectral transform develop in the early nineties. Despite intensive research over several years, there is still quite some way to go before the SAR-ocean inversion reaches the accuracy for the significant wave height obtained from the altimeter.

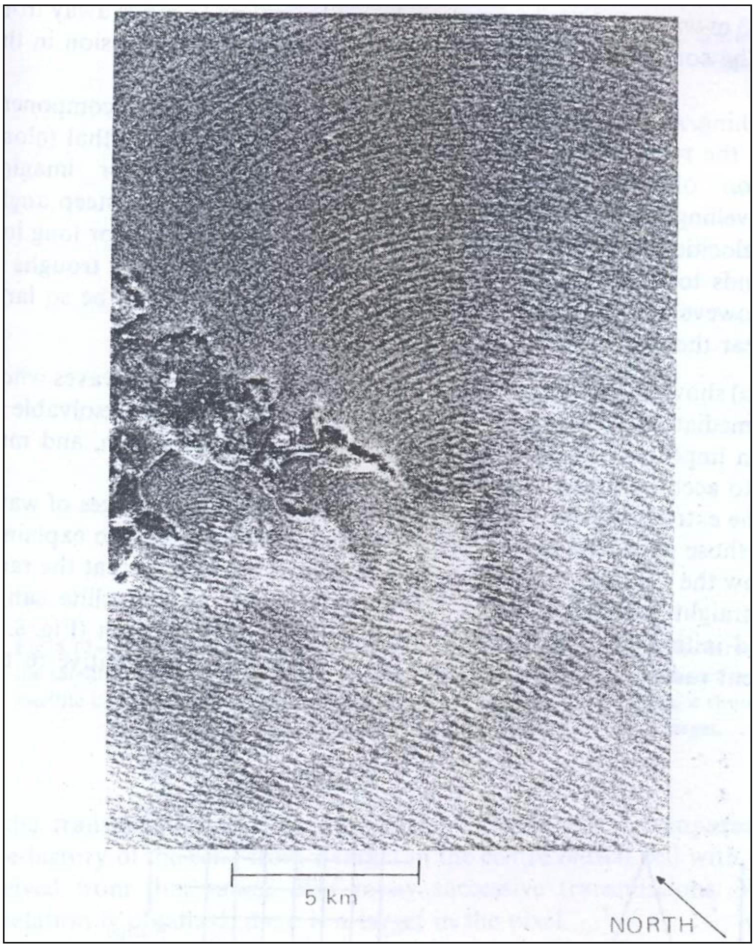


Figure 2.6: SAR image of waves diffracting (Tucker, 1991).

2.4 Currently Available Wave Data Collection in Malaysia

Presently, sources for wave data especially on wave height and wave period available in Malaysia for engineering purposes are limited. Researchers have to rely on the visual observation data and the wave spectrum, which are based on western sea conditions and parameters for engineering applications. A brief information and summary on the status of available wave data collection in Malaysia is presented here.

British Maritime Technology (BMT) provides the data that contains statistics of ocean wave climate for whole globe generally known as Global Wave Statistics atlas, Hogben et al. (1986). The data are presented in terms of probability distributions of wave heights, periods and directions for global selection of sea areas. The data have been derived by a quality enhancing analysis of a massive number of visual observations of both waves and winds reported from ships in normal service all over the world, using computer program called NMIMET (Tucker, 1991). However, there are disadvantages on this data, which is based on visual observation from ship. As ships will try to avoid stormy areas, fewer reports are available from stormy area. Secondly, the whole of South China Sea, Straits of Malacca and the Gulf of Siam are lumped into one area, which is area 62, and hence this will provide inaccurate data for particular area. And thirdly, there is no data for certain critical areas for example Indonesian, Southern Philippines and North Australian sea areas (See Figure 2.7).

Malaysian Meteorological Service (MMS) provides monthly statistics of marine meteorological observation information such as wind waves and swells for example MMS, 1996 (See Appendix C). The wave and wind data collected are derived from marine surface observations reported by ships operating in the Malaysian waters which participated in the World Meteorological Organization Voluntary Observation Ships Scheme, oilrigs and lighthouses. Similar to GWS the data were compiled based on visual observation in which the accuracy is questionable. Also, it is based on voluntary reporting and thus, no data were available for some areas.

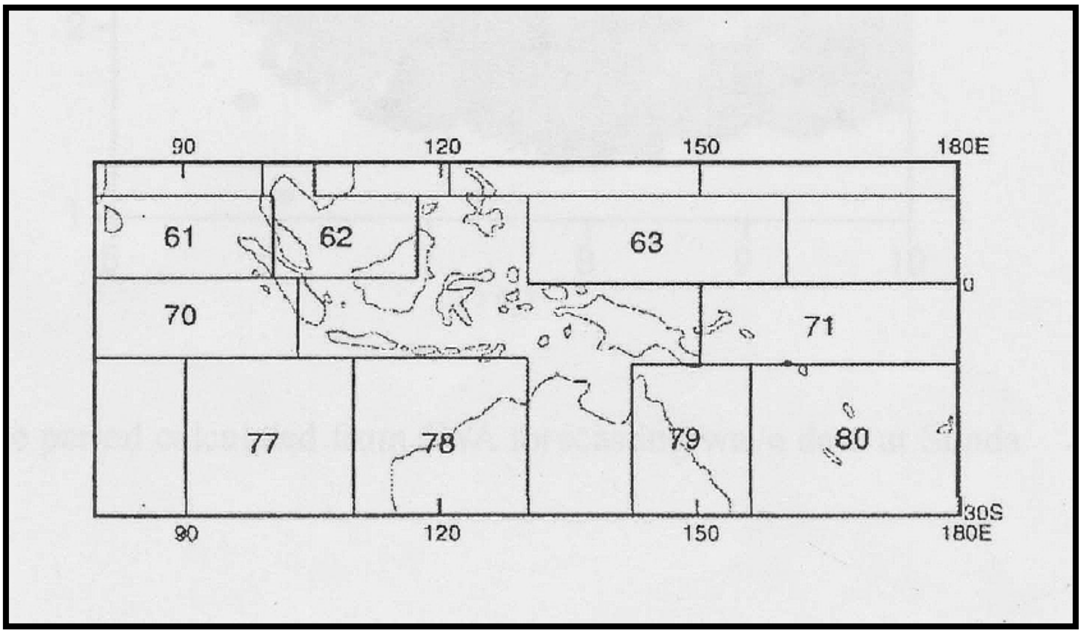


Figure 2.7: GWS data area for Southeast and North Australian Sea (BMT, 1986).

MMS also provides the forecasting wave data and buoy data but there are advantage and disadvantage on these two devices. For example, the buoy was located in the atoll structure in Layang-layang region at Sabah. The waves thus measured are near the atoll instead of the open sea. This *in-situ* reference also suffers from the relatively small number of data sets and the incomplete coverage of the natural range of variations of Hs. MMS also uses a wave-forecasting model called WAM. The data provided by the MMS is presented on monthly charts with individual values in squares of 2^o latitude by 2^o longitude and with forcing by MMS 6-hourly wind field. Errors in wave modeling using WAM are caused mainly by incorrect wind forcing and less by insufficient resolutions (Staabs and Bauer, 1998).

Last but not least, there are also wave database on Malaysian ocean area collected by commercial companies for their operational used, for example the wave database collected by Petronas Carigali Sdn. Bhd. But these wave data are not published and not easily available to the public.

2.5 Summary

Early in this chapter, the importance of the wave data to the marine engineering field, especially seakeeping is briefly described. It is clear that in order to obtain a good and reliable wave data, the raw data collected must be subjected to the precise calculation. A reliable and efficient device will need to be deployed besides the strong and stables structure to withstand the severe waves. This was followed by reviewing the various methods of measurement, observation and forecasting to get the wave data. The advantages and disadvantages of these methods are compared

Presently, only two sources of published data for wave are publicly available in Malaysia; which is Global Wave Statistics (GWS) from British Maritime Technology Ltd., (1986) and the Monthly Summary of Marine Meteorological Observations from Malaysian Meteorological Service (MMS). These data were based on the visual observations covering selected areas mainly along shipping routes. Marine technologists have no viable alternatives and therefore have to rely on these for the time being. Since the available wave data for engineering design calculations for Malaysian ocean and for others requirement are not reliable and insufficient, new effort to collect wave data must be made. One method which is observation and collection of wave data via remote sensing seem to have great potential for development. The next chapter will describe the satellite altimetry technique in detail.

CHAPTER 3

SATELLITE ALTIMETRY

3.1 Introduction

The previous chapter has shown that wave data is an important input to engineering design calculations. A number of sources of wave data and their respective strengthen and weaknesses have been reviewed. One important development in this field is satellite altimetry. This chapter introduces concept and application of satellite altimetry.

3.2 Past and Present Satellite Altimeter

The ‘proof of concept’ of a satellite radar altimeter was established by an instrument carried on SKYLAB in 1973. The United States satellite SEASAT, which was only operational for three months in 1978, was the first satellite with an altimeter to give global coverage, from 72^{o}S to 72^{o}N. An earlier satellite of NASA, GEOS-3 launch in April 1975, carried an altimeter, but it could not store the data on board so it did not provide global coverage. It was not until March 1985 that another altimeter was launched, in the US Navy's satellite GEOSAT. As indicated by its name (GEOdetic SATellite), the satellite's primary purpose was to measure the marine geoid with high precision. Because of the strategic value of the gravity field which is obtainable from the geoid, the data from the first 18 months of observations were classified but some data including wave height values have been released. The classified geodetic mission ended in September 1986, and during October the satellite's orbit was altered, placing it into a 17-day repeat pattern in which it operated until the satellite failed in January 1990; although there was a significant decline in data coverage from about March 1989. Thus GFO has provided, for the first time, several years of near-global coverage of wave data (from 72^{o}S to 72^{o}N) (Carter et al., 1989).

Then, the European Space Agency's ERS-1 was launched in July 1991 into an orbit covering 82^{o}S to 82^{o}N, and is still working well, long after its planned life. The satellite ERS-1 was designed to carry out a wide ranging programme of Earth remote sensing research. To achieve this, ERS-1 operates a suite of remote sensing instruments, including a radiometer, scatterometer, synthetic aperture radar and radar altimeter. It has operated in various repeat-orbits: 3-day, 35-day and currently 168-days. Its replacement ERS-2 was launched in March 1995; but ERS-1 also continue. The US/French satellite T/P was launched in September 1992 into a 10 day repeat orbit. Its primary task is monitoring sea surface height for studying variability of sea level and associated global climate changes, but also provides excellent estimates of SWH but only from 66^{o}S to 66^{o}N (Carter et al., 1989). The main instrument is the dual frequency T/P altimeter, but the satellite also carries the experimental solid state single frequency Poseidon Altimeter which operates 10% of the time. After some degradation in performance of the main T/P altimeter, the back-up B-side altimeter was switched on in February 1999 and took over the T/P altimeter. Then, US Navy's Geosat Follow-On (GFO) altimeter satellite was launched in February 1998 to carry on the mission. The altimeters onboard, ERS-1&2, T/P-POSEIDON and GEOSAT Follow-On (GFO) provided continuous wave height and wind speed measurements over more than 15 years time period. Today, with the successful launches of JASON-

1, in December 2001, and ENVISAT, in April 2002, five altimeters are flying together.

3.3 Altimeter Principles and Techniques

The satellite altimeter is nadir-pointing instrument designed to measure the precise time it takes a radiated pulse to travel to the surface and back again. If the orbital position of the satellite is known relative to a reference surface, then the measured time, converted to range, can be used to derive the elevation of the reflecting surface. A very narrow pulse (<10 ns) is transmitted in order to obtain a small range resolution. In addition to measuring range, the altimeter records an averaged number of return echoes (typically 100), and estimates other geophysical parameters such as ocean wave height and return pulse magnitude. A diagram of the altimeter pulse interaction with a flat surface and the corresponding return echo is shown in Figure 3.1, reproduced from Davis (1992).

As the incident pulse strikes the surface, it illuminates a circular region that increases linearly with time. Correspondingly, a linear increase in the leading edge of the return waveform occurs. After the trailing edge of the pulse has intersected the surface, the region backscattering energy to the satellite becomes an expanding annulus of constant area. At this point, the return waveform has reached its peak and then begins to trail off due to the reduction of off-nadir scattering by the altimeter's antenna pattern. For a rough ocean surface, the leading edge of the return pulse will be "stretched" because scattering from the wave crests precedes the scattering from the wave troughs as the pulse wavefront progresses downward. Thus the width of the return pulse can be related to the height of the ocean waves (Davis, 1992).

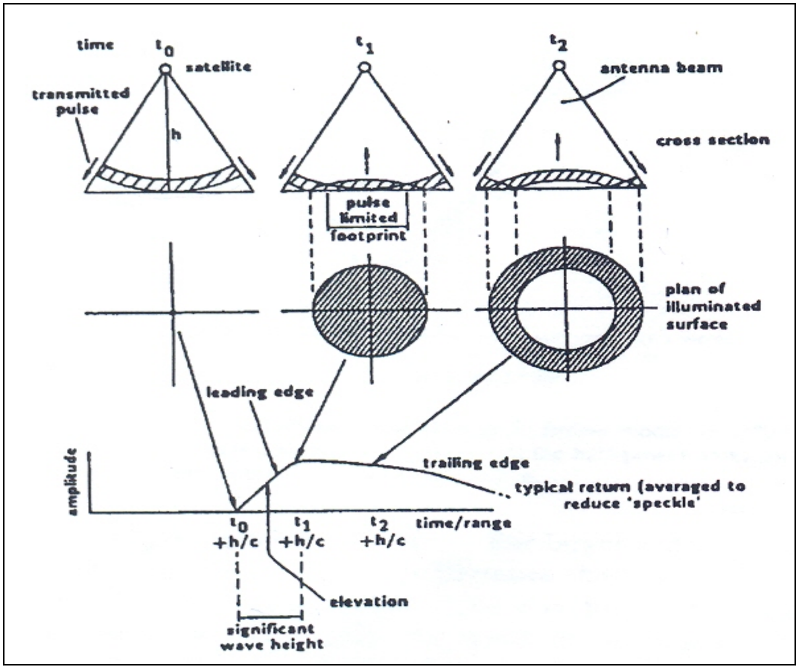


Figure 3.1: Interaction of an altimeter radar pulse with a horizontal and planar surface (Davis, 1992)

For more details explanation, as electromagnetic waves travel through the atmosphere, they can be decelerated by water vapour or by ionisation. Once these phenomena are corrected for, the final range between satellite and ocean surface (R) will be estimated within a 2 cm precision. To do this correction, for example the T/P carries a two-frequency radar altimeter to accurately measure the ionospheric propagation delay and three-frequency microwave radiometer which is able to measure vapour in the troposphere. The ultimate aim is to measure sea level relative to a terrestrial reference frame. This requires independent measurements of the satellite orbital trajectory, i.e. exact latitude, longitude and altitude coordinates. The satellite can be accurately tracked the satellite orbit (S) in a number of ways. The Doris system on board of T/P for example uses a network of 50 ground beacons, worldwide, transmitting to the satellite. It was developed by CNES. Doris uses the Doppler shift on the beacon signals to accurately determine the velocity of the satellite on its orbit, and dynamic orbitography models to deduce the satellite trajectory relative to the Earth. This position is determined relative to an arbitrary reference surface, an ellipsoid. This reference ellipsoid is a raw approximation of

Earth’s surface, a sphere flattened at the poles. The satellite altitude above the reference ellipsoid, distance S, is available to within 3 cm. The sea surface height (SSH), is the range at a given instant from the sea surface to reference ellipsoid. Since the sea depth is not known accurately everywhere, this reference provides accurate, homogeneous measurements. The sea level is simply the difference between the satellite height and the altimetric range:

$$SSH=S-R$$

The SSH value takes account of such effect as the geoid and dynamic topography. The geoid was assuming that the sea surface height would exist without any disturbances (e.g. wind, currents, tides, etc.). It is due to gravity variations around the world, which are turn due to major mass and density differences on the seafloor. The ocean circulation or dynamic topography, which comprises a permanent stationary component (permanent circulation linked to Earth’s rotation, permanent winds, etc.) and highly variable component (due to wind, tides, seasonal variations, etc). The summary for the past and present satellite altimeter measurement precisions and orbit accuracies was shown in Table 3.1.

Table 3.1: Summary of Satellite Altimeter Measurement Precisions and orbit Accuracies (Fu and Cazenave, 2001)

Satellite	Mission period	Measurement Precision (cm)	Orbit Accuracy (cm)
GEOS-3	April 1975 December 1978	25	~500
Seasat	July 1978-October 1978	5	~100
Geosat	March 1985-December 1989	4	30-50
ERS-1	July 1991-May 1996	3	8-15
T/P/POSEIDON	October 1992-present	2	2-3
ERS-2	August 1995-present	3	7-8
Jason-1	December 2001-present	2	2-3

All the altimeter missions listed operate at Ku-band. The choice of frequency is constrained by both the system and operational requirements. Since narrow transmitted pulse (typically 3 ns) is required to achieve a reasonable range precision, high frequency operation will support both the large receiver bandwidth and narrow antenna beamwidth requirements. The upper limit on the operational frequency is constrained by atmospheric attenuation effects that significantly degrade the performance of the altimeter for frequencies >18GHz. In addition to a Ku-band transmitter so that ionospheric propagation delays can be accurately measured. The two-frequency system will produce a subdecimeter range precision so that very small dynamic variations in the ocean surface can be detected.

It is worth to note here that radars cannot directly measure the characteristics of the sea surface. Therefore the second stage is radar data processing; the reason why it is important to have and develop good retrieval algorithm (Panjaitan et al., 2002). In contrast with other microwave instruments, the radar altimeter is supported by a noncontroversial mathematical model relating the return waveform to sea surface interaction. Since the backscatter area seen by the altimeter is restricted to a fraction of a degree around the nadir position, the ocean surface can be approximated by a horizontal planar surface with a large number of scattering facets distributed randomly about the mean sea surface. Moore and Williams (1957) showed that the mean altimeter return waveform could be described by the convolution of two terms,

$$P_r(t) = P_\tau(t)*P_s(t) \tag{3.1}$$

Where $P_r(t)$ is the received power at the satellite, $P_\tau(t)$ is the transmitted pulse profile, and $P_s(t)$ is a term involving the distribution of scatterers, their backscattering properties, and the antenna gain. From this convolutional form, many researchers like Barrick (1972), Brown (1977) and Lipa and Barrick (1981) obtained a model to describing the altimeter return waveform.

The present ~4 cm state-of-the-art overall accuracy of the surface height estimates *h* has been achieved through major technological advancements in precision orbit determination and a dedicated effort to improve each of more than 40 sensor and geophysical algorithms. This attention to algorithm improvements has transformed altimetry from semi quantitative measurement of sea-surface height for which the distinction between measurement errors and geophysical signals was sometime difficult to discern, to a highly quantitative measure of sea-surface height variability that is providing insight into the wide range of dynamical processes. A major benefit of the high degree of accuracy is that it is no longer essential for users to be deeply versed in all of the idiosyncrasies of satellite altimetry. Altimetry has thus become a standard tool for oceanographic research (Fu and Cazenave, 2001).

3.4 Altimeter Estimation

Several parameters can be derived from the satellite backscatter. For example, TOPEX/Poseidon can produce data of SWH, windspeed (U), sigma0 (σ^0), sea surface height, sea surface anomaly, water vapour content, total electron content and others geophysical data. In this section, the explanations only focus on SWH and wind speed according to the scope of this study. In addition, the derivation of wave period from this estimation will be explained briefly.

3.4.1 Significant Wave Height (SWH)

Significant wave heights, SWH are a measure of the general sea state, an ‘average’ value of the prevailing conditions. It was originally defined, about fifty years ago when only visual observations could be obtained, as the mean height of the one-third highest individual waves, crest to trough. This was considered to give about the same values as an experienced ‘seaman’s estimate of ‘mean’ wave height. With the development of instruments which measured time series of the sea surface elevation (η), SWH was redefined in terms of the statistical variance of the sea surface:

$$SWH=4\sqrt{<\eta^2>} \qquad (3.2)$$

Where, $<\eta^2>$ is the surface variance. The '4' was introduced so that, for a narrow-band sea, the old and new definitions have the same value. Note that $<\eta^2>$ can be measured either over an area of the sea surface at any instant or over a period of time at a single position. Assuming statistical stationary in both space and time over the area and period of measurement, then the spatial and temporal definitions turn out to be numerically identical. So this definition of significant wave height can be equally applied to, say time series of η from buoy or to a stereographic photograph of the sea surface – or to a 'snap shot' of the sea surface from a radar altimeter (Carter et al., 1989).

Radar altimeters fitted in earth-observing satellites are mounted to point vertically downwards. Their primary purpose is to measure the height of the satellite above the sea surface and hence provide information about the geoid; but the shape of the return pulse (σ_s) also gives an estimate of the sea surface variance, $<\eta^2>$, and hence the width of the leading edge is used to estimate significant wave height (SWH), where;

$$SWH = 4 * \sigma_s \qquad (3.3)$$

and the range to the mean surface is associated with the half-power position on the leading edge of the waveform. Essentially, the higher the waves in the footprint of the radar pulse, the more spread-out the time of arrival of the front of the return pulse. Thus, the significant wave height is estimated only from that portion of the sea surface which contributes to the leading edge of the return pulse. Returns further away from nadir, which forms the trailing edge of the return pulse, are not taken into account. The effective footprint, from which SWH is derived, is around 5 – 10 km, depending on the height of the satellite and on sea state (Carter et al., 1989). There is quite different for ERS-1/2b Fast Delivery Products (FD) which is the estimated on board- the conversion to the SWH is done using a look-up table. This table is derived by a comparison of the altimeter derived SWH with ECMWF wave models (WAM) prior to an assimilation (Tilo and Stephan, 2000).

A problem in estimating SWH is that individual returns from the sea surface are severely contaminated by noise. To reduce the effect of this, values of SWH from individual pulses, which are transmitted at 1000 Hz, are averaged to obtain 1 s values which are transmitted to ground stations. In practice, 50 or 100 pulses are averaged, and the mean over 1 s of these averages is transmitted; the standard deviation of these averages is also transmitted, and provides useful quality check. The satellite orbits the Earth in around 100 minutes, which gives the speed of the radar ‘footprint’ over the ocean as about 7 km/s, so estimates of significant wave height are obtained at 7 kilometre intervals along the satellite track (Carter et al, 1989). This is a reason for satellite altimeter only provides the SWH not the sea surface height (SSH).

In fact, when compared against in-situ measurements this derived estimate of significant wave height gives a residual root mean square of about 0.3 m, close to the estimated accuracy of the in-situ measurements themselves. The altimeter has the added benefit of being largely unaffected by extreme sea conditions (except during very heavy rainfall, which attenuates the radar signal), whereas buoy and ship data can become increasingly unreliable in high seas. However, the T/P SWH data employed have been corrected for the sea state bias, static atmospheric pressure and various other intervening factors-as described in (Glazman et al., 1996). The geoid and tidal (solid Earth and ocean) variation have also been removed from the data. The residual error of SSH measurements is presently believed to be about 5 cm. One particular component of this error is of special concern. This component arises from the remaining uncertainty in the satellite orbit and could introduce a slight different in the SSH values on difference satellite passes up to 3 cm.

3.4.2 Wind Speed

An estimate of surface wind speed is generated from the radar altimeter measurement of normal incidence surface backscatter (σ_0), which is itself derived from the power of the reflected radar pulse received back at the altimeter. The physical principles behind this wind speed measurement are that the wind blowing over the ocean surface generates small centimetre scale ripples at a similar wave length to the radar, ~2.3cm for Ku band, which reduce the power of the signal reflected directly back up toward the altimeter and hence reduce the measured backscatter (σ_0). The algorithm used to convert σ_0 into surface wind speed was derived empirically from co-located measurements of altimeter σ_0 and buoy measured wind speed. The algorithm in current, almost universal, usage was derived by Witter and Chelton (1991) for Geosat data, and has since been applied to ERS-1, ERS-2 and T/P data. When compared against in situ wind measurements, altimeter wind speeds show a residual root mean square (r.r.m.s) of 1.5 ms^{-1} or better. Recent studies have developed improved wind speed algorithms which include a dependence on both σ_0 and significant wave height and have shown (r.r.m.s) accuracies of close to 1.2 ms^{-1} (Cotton, 1998).

Estimating surface wind speed presents more difficulties than for SWH. Firstly because wind speed is not the only geophysical parameter interacting with the altimeter backscatter coefficient, which is rely the main operational altimeter wind speeds algorithm. Other parameters such as SWH, wave age and fetch induce large scatter on altimeter wind speed estimates. Secondly σ_0 depends strongly on altimeter electronics, and absolute calibration is presently not available, though being under investigation within the ENVISAT RA-2 validation activities. Thirdly, small variation of σ_0, as for instance 0.2 dB for ERS-2, induces significant errors on retrieved wind speed. Because the relation between sigma0 and wind speed is non-linear the obtained statistical slope and intercept cannot be used to correct accurately the altimeter wind speed (Queffeulou, 2003).

3.4.3 Derivation Wave Period

Satellite altimeter does not provide the wave period parameter. Recently, there is an effort among the scientists to define a non-scaled the wave period. However, the derivation of wave periods from altimeter data is still in its early development (Carter et al., (1992); Davies et al., 1997). Large scale verification is necessary before an altimeter wave period parameter reaches a suitable stage of maturity to enable its acceptance by the research community (Fu and Cazenave, 2001). For the time being, only three approaches have been suggested to derive the wave period in term of zero upcrossing.

a) Davies Method

A theoretical algorithm was developed based upon the theory of wave statistics, and on the relationship of the moments of the wave spectra to the wave parameters that can be measured by a radar altimeter (significant wave height and radar backscatter). Further empirical developments resulted in the inclusion of a wave age dependent term in the final proposed algorithm. However, some sea state dependence reminded and it was found that the algorithm could not provide reliable estimates in conditions where moderate to large wave heights and low winds occurred together. It was therefore recommended that the use of the algorithm should be restricted to conditions with wind speed above 2 ms^{-1} and altimeter derived pseudo wave ages of less than 13.

b) Hwang Method.

Recent study of tilting effects on radar backscatter indicates that the altimeter wind speed (U) measurement are accurate to better than 1 m/s, and are within the accuracy of buoy measurements. The combination of wind speed and wave height further yields the information of wave period (T). It is therefore quite feasible that we can obtain the three critical parameters of a wave field (H, T and U) from satellite altimeter and can provide a long-term monitoring of the wave climate of the world ocean based on assumptions of a “saturated” sea conditions and negligible swell.

c) Gommenginger Method.

The existence of sea state development effects on the retrieval of altimeter wind speed is well documented; and few earlier studies have already considered the development of altimeter wave period model. However, the sea state dependence in these semi-empirical models spanned only a small range of environmental conditions. The purely empirical wave period algorithm developed on the basis of the largest to-date dataset of collocated altimeter/buoy spectra measurements.

Full description of the derivation methods will be further explained in Chapter 4.

3.5 The Accuracy of Satellite Wave Data

The use of remotely sensed wind and SWH should potentially lead to more refined wind and sea state field analysis at global and regional scales. Accurate calibration is important for all applications, but particularly so for climate studies, where any bias in the altimeter wave heights, even of one or two percent, would effect the statistics. This would then render the database useless for studies of climate change in which trends of one or two percent per annum in annual mean wave heights have been found to be of significance (Cotton et al., 2004). It is thus of crucial importance to analyse the consistency between the various data sets and the characterization of their respective weaknesses (Queffeulou et al., 2003).

However, there are problems in this purpose. Firstly, it is due to insufficient in-situ data used for calibration or the large distance between the in-situ sensors and measurements. Only a few locations worldwide, oil platforms or buoys, exist for calibrations. The limited geographical distribution causes problems due to the different sea state behaviour in different regions. In some studies ECMWF wind fields are used for calibration, but the local wind may vary more rapidly than computed from the models (Tilo and Stephan, 2000).

Secondly, many authors have carried out calibration and validation studies on wind and wave measurements from spaceborne altimeters, using a variety of data sets and techniques. However, because of these authors have used different procedures and different validation data sets, it is difficult to combine their results to form a single combined assessment of the relative accuracies and reliabilities of the measurements from the different altimeters. They also very rarely consider the nature of the errors in the individual data sets before considering which techniques are most appropriate (Cotton, 1998). This confusing situation exists across altimeter and buoy data sets, and creates a major obstacle to the full exploitation of these data.

3.5.1 Validation with Instrumental Measurement

In various studies, data from altimeters were validated against in-situ observations from buoys. Uncertainties still remain about which of the SWH data sets agrees more closely with the “true” sea state. On average, the accuracy of SWH from altimeters was repeatedly confirmed to be below the commonly used error boundaries of 0.5 m or 10% (whichever is larger) in the range 1 to 20 m. Note that a recent study shows that SWH from T/P are, on average, 5% lower than those from the buoys, with RMS scatter about the mean relation of 30 cm. It is also found an underestimation of SWH from ERS-1 against TOBIS buoys (Staabs and Bauer, 1998).

However, many comparison studies have shown excellent agreement of the wind and wave measurements between satellite altimeters and ocean surface buoy data (Carter et al., 1989; Tilo and Stephan, 2000; Panjaitan et al., 2002; Hwang et al., 1997b; Hwang et al., 1998). For example, a comprehensive comparison of wind speed and wave height between the T/P altimeters and 14 moored buoys along the west coast of Canada show the excellent agreement between the altimeter and buoy measurements of the significant wave height is found for the nine buoys in exposed positions. The excellent agreement on the wave height measurement is also confirmed in the Gulf of Mexico stations. The comparisons of the significant wave height, wind speed and characteristic (average) wave period derived from the T/P Ku-band altimeter and NDBC buoy data points within 10 km spatial lags shows the average ratio and one standard deviation of wave heights, wind speeds and characteristic wave periods are 1.01±0.14, 0.95±0.11, 1.06±0.13, respectively. This means that the measurements from the two systems are essentially equivalent (Hwang et al., 1997b).

For coastal regions, the agreement is clearly not as good. The large variation in coastal comparison is attributed to the local variation of the wave conditions due to the close proximity to the shoreline. It is further shows that in the exposed locations, the R.M.S data scatter is greatly reduced when the spatial distance between T/P and buoy observations is reduced to 10 km (Hwang et al., 1997b).

3.5.2 Validation with Wave Model/ Hindcast Data

The comparison of long term wave height probability between the satellite data and the forecast data in the southern parts of Sunda Strait and Lombok Strait was shown that the data is very similar, and it turns out that accuracy is not inferior in satellite data compared with the in-situ data (Sakuno et al., 2003). Hwang et al., (1999) analyzed the T/P altimeter wind and wave measurements in the Yellow and

East China Seas. The results show that model simulations are in good agreement with T/P measurements in terms of the local mean and standard deviation of the variables (wave height and wind speed).

The others study of wave and wind statistics derived from T/P measurements and the numerical output of WAM and NCEP (National Centres for Environmental Prediction) to drive the global and regional wave model grids, show that the average properties of wind speeds and wave heights between the numerical simulation and remote sensing measurements are in good agreement, within 10 percent in most cases for both the mean and standard deviation of these average quantities. But wave heights for WAM hindcast are slightly higher than the T/P data. In general, the annual average predicted by the WAM model agrees very well with the T/P measurement. In cases with discrepancies, the disagreement in wave height appears to correlate with disagreement in wind speed or wind stress used to drive the model (Hwang et al., 1999). However, this is disagreed by Staabs and Bauer (1998) where the SWH from WAM is seen to be lower than SWH from T/P for SWH value higher than 2.7 m and vice versa for SWH lower than 2.7 m. Staabs and Bauer (1998) also suggest that the SWH from T/P is overestimated at the high sea state compared to SWH from WAM.

For wind speed, the remotely sensed winds tend to be underestimated at low winds and overestimated at high winds. The overall bias, r.m.s difference correlation coefficient and symmetrical regression coefficient are about -1.50 m/s, 2.90 m/s, 0.75 and 1.16, respectively. The highest bias values, about 5^0, are found at low wind speeds (less than 4 m/s) (Queffeulou et al., 2003). This is different from Hwang et al. (1999) result which is the average wind speed used in WAM is in general higher than the T/P observation. However, the inter-calibration of altimeters is an important issue for improving the analyses and forecast when assimilating several altimeters in a numerical wave model. In order to consolidate these results, longer assimilation period will be considered (typically one month) (Lefevere et al., 2003).

3.5.3 Validation with Crossover Satellite Altimeter

Collocation procedures and analysis developed at LOS-CERSAT are applied to validate ENVISAT RA-2 and JASON-1 SWH, sigma0 and wind speed measurements, using buoy, ERS-2, T/P and GEOSAT FO altimeter data. ENVISAT and JASON Ku SWH are shown to be underestimate SWH, but for sigma0 and wind speed parameter it shown positive biases and well correlated respectively with GFO, T/P or ERS-2 (Queffeulou, 2003). According to Queffeulou et al., (2003), T/P altimeter and QuickScat data are collocated (10 km, 30 min) from July 1999 to August 2002. Results are given for two areas: one including the Mediterranean Sea, the Black Sea and Caspian, the other one over an off-shore Western Atlantic area. The bias between QuickScat and T/P is only 0.06 m/s in Atlantic Ocean (0.97 m/s std) but 0.63 m/s in the Mediterranean Sea (0.91 m/s std). This difference between the two areas is confirmed when binning according to QuickScat wind speed, T/P underestimating the wind speed in the Mediterranean Sea. Main difference is the fetch, resulting in different sea state wave age.

Other experiments by Queffeulou et al., (2003) was to proved that the buoy equipped with a Global Positioning System (GPS) receiver has the potential to greatly increase the number of locations where satellite calibrations can be performed since GPS now provide three- dimensional positioning coverage nearly anywhere on or above the surface of the earth. Traditionally satellite calibrations have been limited to locations such as islands or offshore platforms where conventional tide gauges can be used. Two GPS software packages were used in these calibration experiments: Kinematic and Rapid Statis (K&RS) develop by G.L. Mader, and GIPSY-OASIS II (GOA II) developed at the Jet Propulsion Laboratory. K&RS was developed specifically for high precision kinematic positioning. GOA II was developed for more general applications such as high precision geodesy (using global scale networks) and GPS based orbit determination for low earth orbiters. The experiment was conducted off the California coast near the Texaco off-shore oil platform, Harvest, during cycle 34 of T/P observational period. The bias in the T/P altimeter was found to be was -14.6±4 cm using K&RS and 13.1±4cm with GIPSY OASIS II.

Then, the statistical intercomparison of SWH retrieved operationally from ERS-1 SAR wave mode spectra with altimeter-derived SWH from T/P done by Bauer and Heimbach (1998) reveals a good agreement among the data. The correlation of SWH of ERS-1 altimeter with SWH of T/P is 0.83. The r.m.s deviations of collocated data sets are equal to 0.74 m. From the research done by Staabs and Bauer (1998) the SWH from T/P are constantly larger than the SWH from ERS-1 about 0.3. This gives evidence that SWH from T/P contain more and/or higher values of SWH than from ERS-1. In regions of low sea states, such as the tropical oceans SWH from ER-1 values were found to be higher than SWH T/P values. Cotton and Carter (1994) also found that the SWH from ERS-1 to be smaller than SWH from T/P, which seem to confirm this results.

3.5.4 Validation with Visual Observation

Comparison of monthly mean wave heights between visual observation from ship and T/P shows that wave heights from satellite data overestimated to visual observation data from ships. This could be due to lack of wave data when sea is rough. However, on the whole, correlation is high and it turns out that the T/P data processed in JPL observed wave height in accuracy high on the average (Sakuno et al., 2003). More than that, the r.m.s of the differences of collocated radar altimeter wind speeds and visual wind speed estimation in the meteorological database is ±1.8 m/s for ERS-2/FD and ±1.6 m/s for T/P (Staabs and Bauer, 1998).

3.6 Application and Present Study of Satellite Altimeter

Presently, satellite altimetry is being applied in a number of areas. The following section describes some examples.

3.6.1 Direct Use of Satellite Measurement in Shallow Water.

The spatial resolution of satellite altimeter data is no better than 7 km or so along the track. Further, generally, altimeter data are only useful when the satellite moves from the sea towards the coast as measurements are often either missing or biased for the first few measurements after passing from land to sea. However, in some cases, when shallow water area is rather large compared to the altimeter resolution or the satellite track is oriented alongshore, then altimeter can nevertheless be very useful. An example of the former type is given first, from the North Sea, which is a shallow basin of large extent. Next example where the satellite is oriented alongshore is given from Norwegian waters. In fortunate situations, it is possible to use altimeter data for model verifications also in coastal waters as the example in Norway 1994 (Harald and Stephen, 1999).

3.6.2 Studies of Temporal and Spatial Representatively

In more remote and data sparse regions of the world the altimeter provides an efficient means to extend short period wave measurements both temporally and spatially. In connection with a feasibility study for building a Tapered Channel wave energy converter and power plant on the southern coast of the Indonesian island

Java. Nevertheless, altimeter data have often been employed over the years also in more data rich waters such as North Sea and Nowegian Sea, for example, evaluate the spatial representativesness of a long term measured series from one location for a second site in the same area. And also, altimeter data were used together with wave model data to better document the longer term wave climate and to have a re-look at the extreme predictions (Barstow and Krogstad, 1993).

3.6.3 World-wide Wave Climatology

The fact that altimeter data are available globally over a regular “net” (the ground tracks), allows us relatively easily make global comparisons of wave conditions. An example of one such application was in connection with development of the Norwegian Con Wec wave energy converter. T/P data were recently used to estimate the wave energy resources along all coasts globally (Barstow et al., 1998). Two years of the altimeter data were used in constructing the global map of the available wave energy resources in deep water. For example various data sets from the South Pacific islands with varying exposure to wind seas and swells, various Norwegian data sets and also data from a swell dominated wave climate off Portugal. Another example is the climatologies application at the Gulf of Mexico and Yellow, East China Seas and European Sea.

3.6.4 Coastal Wave Statistics

Both in wave energy and other coastal applications, offshore wave conditions will not be representative of conditions at the coast. Although spatial gradients along-coast offshore is relatively small in most cases, the transformation in wave conditions from deep water in to the coast may be large even over a relatively short distance. In some cases, if one is lucky to have a satellite track passing from the offshore and close to the site of interest, it is possible to make a simple transfer function from deep water to the site. However, this is only useful where one can accept a spatial resolution of no better than 20km or so. Nevertheless, this method is often useful to give a quick, rough estimate of the wave conditions at a site. In order to provide more accurate wave conditions at a coastal location, in the absence of on-site measurements, satellite wave measurements are not sufficient alone and the best approach is to validate and, if necessary, calibrate data from an existing global or regional wave model archive using satellite data. The resultant time series can then be used as input to a suitable shallow water wave model to perform the transformation to the coastal locality of interest. For example 10 year archive (1986-96) global wave model from the UK Met. Office. Other existing global archives, which could be used alternatively, are those derived from the Fleet Numerical Spectral Global Ocean Wave Model (SGOWM) and the global WAM model operated by the European Centre for Medium-Range Weather Forecast (ECMWF) (Harald and Stephen, 1999).

3.6.5 Wave Atlases

Traditionally, wave atlases based on visual observations have provided wave statistics covering the global oceans. With many years of satellite data available, there now exist several global wave atlases based on satellite altimeter data. However, it was early realised during the development of the World Wave Atlas (WWA) that many users of wave data are interested in wave statistics for only one or few areas around the world. Therefore, it was decided that rather than producing one atlas for the whole globe with low resolution and accuracy, WWA should provide basically all available data for smaller areas at the highest resolution and accuracy. Thus, World Wave Atlas is, in fact, a composite of atlases, including every maritime country world-wide.

3.6.6 Wave Model Validation

With an along-track resolution of 7 km, the spaceborne measurements represent a valuable addition to the study of regional oceanography. The spatial resolution of the spaceborne altimeter in the groundtrack direction is comparable to or better than of the numerical models used for regional simulations. One of the major issues in the numerical hindcasting and forecasting is the difficulty of validation and verification. While comparisons with point measurements from discrete and sparsely distributed wave buoys provide some degree of statistical confidence, the spatial distribution of the modeled wind and wave fields cannot be easily assessed (Hwang et al., 1999). Spaceborne altimeter outputs have been used for model validation, data assimilation and/or evaluation of model performance with different wind products. For example, errors in wave modeling using WAM are caused mainly by incorrect wind forcing and less by insufficient resolutions. Since August 16, 1993, SWH from the ERS altimeter have been assimilated into the WAM model at ECMWF (Staabs and Bauer, 1998).

3.6.7 Present Study

It cannot be denied that satellite altimeter application in marine area in Asia is very limited and still in initial stage of study. A group of researchers lead by Yuji Sakuno from Hiroshima University in Japan (Sakuno et al., 2003) carried on a research in Indonesian domestic sea due to the lack of available wave data there. Their objective was to create the new methods of wave data collection based on satellite data. They used the method develop by Hogben et al. (1986) to estimate the wave period from satellite altimeter data with the relationship of joint log-normal probability distribution which is fitted to each set of measured data. The second study was done by the researchers from Indonesia lead by James P. Panjaitan (2000) from Kampus IPB Darmaga, Bogor. They also had the same objective with the

Japanese researcher which is to develop an alternative for wave data collection in Indonesia domestic sea using the satellite altimeter data. But the difference is they are not interested to estimate the wave period from satellite altimeter data and more focus on the validation of the data.

3.6.8 Online Wave Database

At this time, all the satellite altimeter data have been published in the internet for easier access of user by their domain server. For example, T/P data are the Merged Geophysical Data Record (MGDR) distributed by CNES AVISO and NASA/JPL offers on the internet in the form of text data describe latitude, longitude and significant wave height (SWH). ERS altimeter data are the ESA Ocean Product (OPR) processed and distributed by the French Processing and Archiving Facility (CERSAT, 1996). The GFO data are the Intermediate Geophysical Data Record (IGDR) distributed by John Lillibridge (NOAA/NESDIS/ORA) via the GFO calibration validation dedicated website (Queffeulou, 2003).

Satellite altimeter also can be accessed from the other website, for example, in the US, NOAA’s (National Environmental Satellite, Data and Information Service (NESDIS). UCDS and Scripps Oceanographic Institution runs the Coastal Data Information Program where information on the net provides a synopsis of the latest coastal conditions including wave, wind and temperature measurements and even an El Nino swell forecast. In Europe, the Committee on Earth Observation Satellites (CEOS), of which ESA is a major member, serves as a focal point for application of satellite measurements. The organisation’s home page at http://ceos.esrin.esa.it:8000/infosys has effective search facilities and links, e.g., to the national earth observation networks within the organisation. The Centre for Earth Observation (CEO) is another European initiative to encourage the wider use of information generated by satellites. Its web site contains much useful information, links and actual application cases for remote sensing data including ocean waves.

Several university groups, in particular the Southampton Oceanography Centre in the UK are active within altimeter research. There are also commercial companies, which provide analyses based on satellite wave data. Satellite Observing Systems sell both near real-time wind and wave information and global climate analyses. The French company MeteoMer has cooperation with Ifremer developed the Cliosat wave atlas, but limited information is available on the net. In Norway, Oceanor ASA is selling the World Wave Atlas and in the Netherlands the ARGOSS Company is developing several applications of satellite data (Clayson, 1989). It is important to note that, most of these satellite wave data websites focused in Western Ocean area and some of them also provided the satellite wave data for a whole world but for the client or user, they must buy or purchase to get the data whereas we can use the data freely from the public domain servers. Hence, there is a great need to develop Malaysian ocean satellite wave database to provide a reliable wave data at low cost and also to publish on website for others to access.

CHAPTER 4

METHODOLOGY

4.1 Introduction

This chapter describes the methodology to derive the Malaysian ocean wave database in the form of scatter diagram for engineering purposes from the satellite altimetry observation. The summary of the procedures is shown in Figure 4.1. It starts with downloading the satellite wave data from internet and then the data is sorted within Malaysian ocean areas. Then the data is subjected to two procedures, first to calculate the probability distribution of significant wave height (SWH) and second to derive the wave period from the other wave parameters given by satellite wave data. After that the joint probability distribution between SWH and wave period (Hs-Tz) will be calculated. And finally, this joint probability distribution will be tabulated in the form of scatter diagrams similar to the format used by Global Wave Statistic (GWS). These procedures were performed automatically by using a simple computer program.

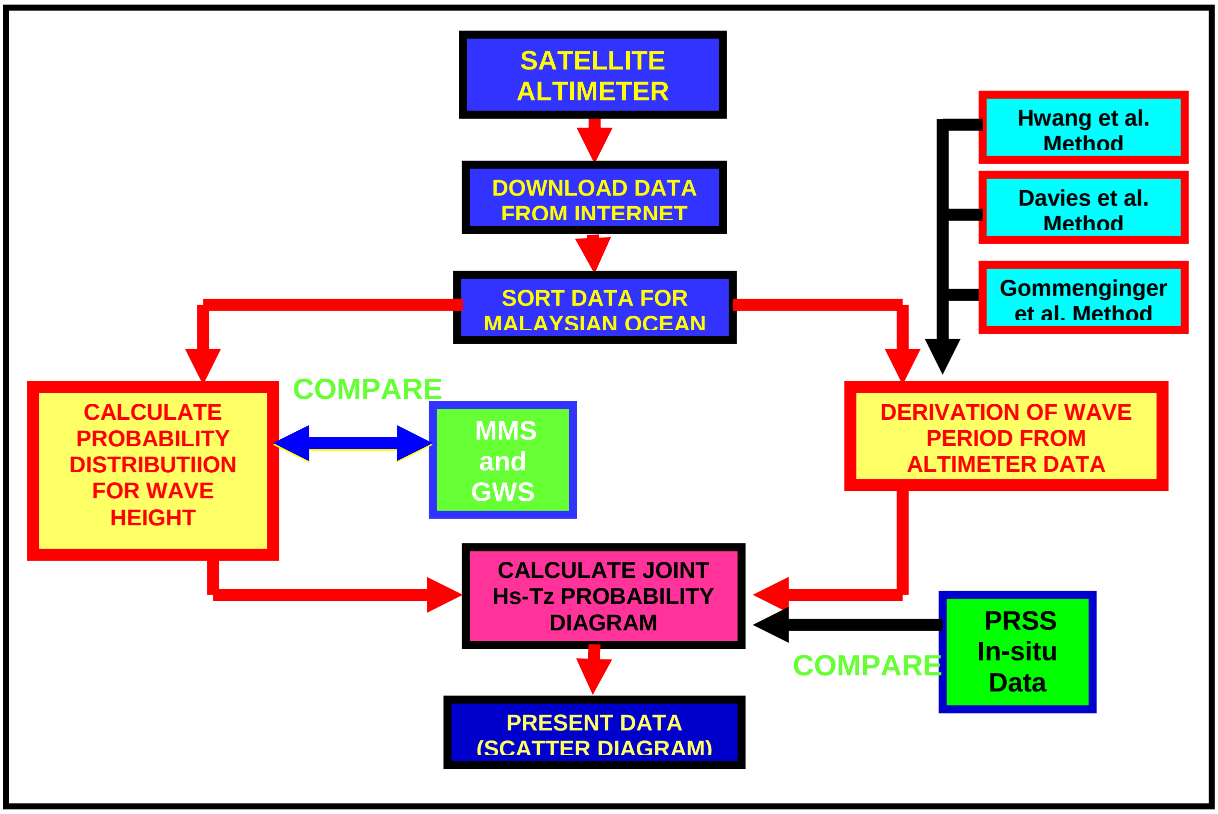


Figure 4.1 : The flowchart of procedure to develop Malaysian ocean wave database using satellite altimetry

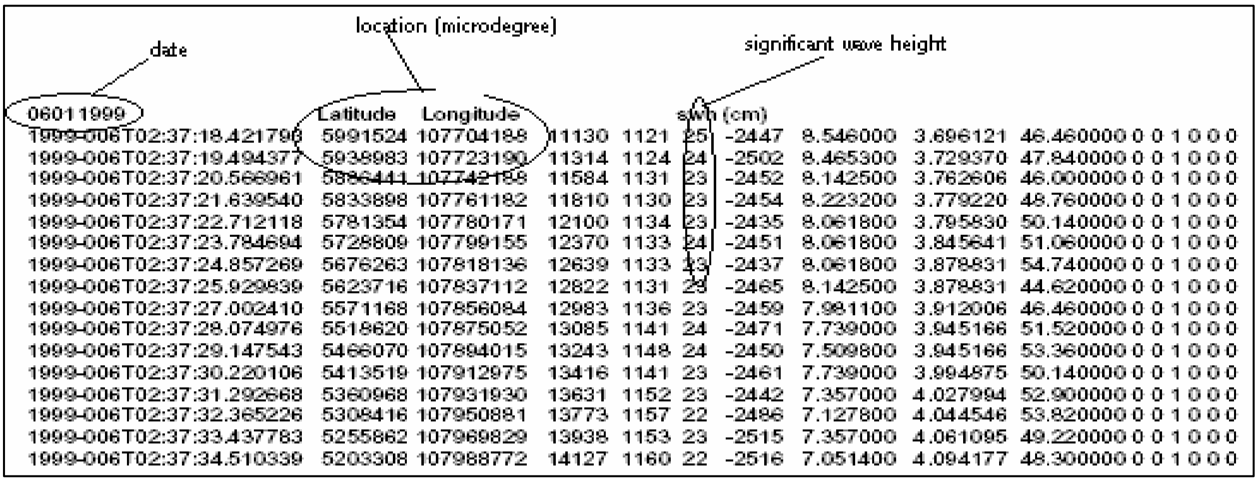
4.2 Downloading Satellite Wave Data from Internet

In this research, one set of satellite wave data was taken from satellite altimetry collected by TOPEX/Poseidon in period of May 1997 until August 2003. These data are the text data containing date, time, location SWH and etc (See Figure 4.2). The data is given in the form of SWH for sea surface height which is defined as the mean height of the highest of 1/3 of the waves, wind speed and also the sigma0.

This satellite is a joint program between NASA and the Centre Nationale d’Etudes Spatial (CNES). These data are available at JPL website (Physical

Oceanography Distributed Active Archive Center (PO.DAAC) Home Page) and can be downloaded free from PODAAC website. TOPEX/Poseidon was launched on 10 August 1992 and remains fully operational. On 15 August 2002 (cycle 365 pass 111) the T/P satellite began its drift phase to a new orbit in preparation for the Tandem Mission. The drift phase lasted until 16 September 2002 ending with cycle 368, pass 171. Data for cycle 368, pass 172 and later are on the final fixed tandem mission ground track, which is interleaved with the Jason-1 (launched on 7 December 2001) ground track, doubling the temporal and spatial coverage.

On board, the TOPEX/POSEIDON satellite caries a dual-frequency radar altimeter (TOPEX), a single-frequency solid-state altimeter (POSEIDON), the TOPEX Microwave Radiometer (TMR), a DORIS tracking system receiver, a laser retroreflector array, and a Global Positioning System (GPS) receiver. Careful intercalibration has produced a single, combine T/P altimeter data set. At single latitude the satellite ground track is 2.8° apart in longitude, which is repeated every 9.92 days (typically called a 10-day repeat cycle). A set of corrections is applied for orbit errors, atmospheric delay, tides and sea state effects (Cipollini et al., 1997). The rms accuracy of the sea surface height retrieval is about 2-3 cm (Cheney et al., 1994).



```
06011999                          Latitude  Longitude                swh (cm)
1999-006T02:37:18.421796  5991524 107704188  11130 1121 25  -2447  8.546000  3.696121  46.460000 0 0 1 0 0 0
1999-006T02:37:19.494377  5938983 107723190  11314 1124 24  -2502  8.465300  3.729370  47.840000 0 0 1 0 0 0
1999-006T02:37:20.566961  5886441 107742188  11584 1131 23  -2452  8.142500  3.762606  46.000000 0 0 1 0 0 0
1999-006T02:37:21.639540  5833898 107761182  11810 1130 23  -2454  8.223200  3.779220  48.760000 0 0 1 0 0 0
1999-006T02:37:22.712118  5781354 107780171  12100 1134 23  -2435  8.061800  3.795830  50.140000 0 0 1 0 0 0
1999-006T02:37:23.784694  5728809 107799155  12370 1133 24  -2451  8.061800  3.845641  51.060000 0 0 1 0 0 0
1999-006T02:37:24.857269  5676263 107818136  12639 1133 23  -2437  8.061800  3.878831  54.740000 0 0 1 0 0 0
1999-006T02:37:25.929839  5623716 107837112  12822 1131 23  -2465  8.142500  3.878831  44.620000 0 0 1 0 0 0
1999-006T02:37:27.002410  5571168 107856084  12983 1136 23  -2459  7.981100  3.912006  46.460000 0 0 1 0 0 0
1999-006T02:37:28.074976  5518620 107875052  13085 1141 24  -2471  7.739000  3.945166  51.520000 0 0 1 0 0 0
1999-006T02:37:29.147543  5466070 107894015  13243 1148 24  -2450  7.509800  3.945166  53.360000 0 0 1 0 0 0
1999-006T02:37:30.220106  5413519 107912975  13416 1141 23  -2461  7.739000  3.994875  50.140000 0 0 1 0 0 0
1999-006T02:37:31.292668  5360968 107931930  13631 1152 23  -2442  7.357000  4.027994  52.900000 0 0 1 0 0 0
1999-006T02:37:32.365226  5308416 107950881  13773 1157 22  -2486  7.127800  4.044546  53.820000 0 0 1 0 0 0
1999-006T02:37:33.437783  5255862 107969829  13938 1153 23  -2515  7.357000  4.061095  49.220000 0 0 1 0 0 0
1999-006T02:37:34.510339  5203308 107988772  14127 1160 22  -2516  7.051400  4.094177  48.300000 0 0 1 0 0 0
```

Figure 4.2: TOPEX/Poseidon text data containing the date, location, SWH and etc (ftp://podaac.jpl.nasa.gov/sea_surface_height/topex_poseidon/images/).

4.3 Sorting Data for Malaysian Ocean

The data for Malaysian Ocean will be sorted based on latitude and longitude in text data, which is 0° N- 10° N for latitude and 94° E-120° E for longitude. The data set were divided into smaller areas, 2º x 2º for latitude and longitude which is similar as MMS Monthly Summary of Marine Meteorological Observations report grid (See Figure 4.3). Indeed, the region by 2º in latitude by 2º in longitude for averaging the satellite data is enough in reducing the spatial difference according to Carter et al. (1989). The 48 areas are labelled for easier recognition.

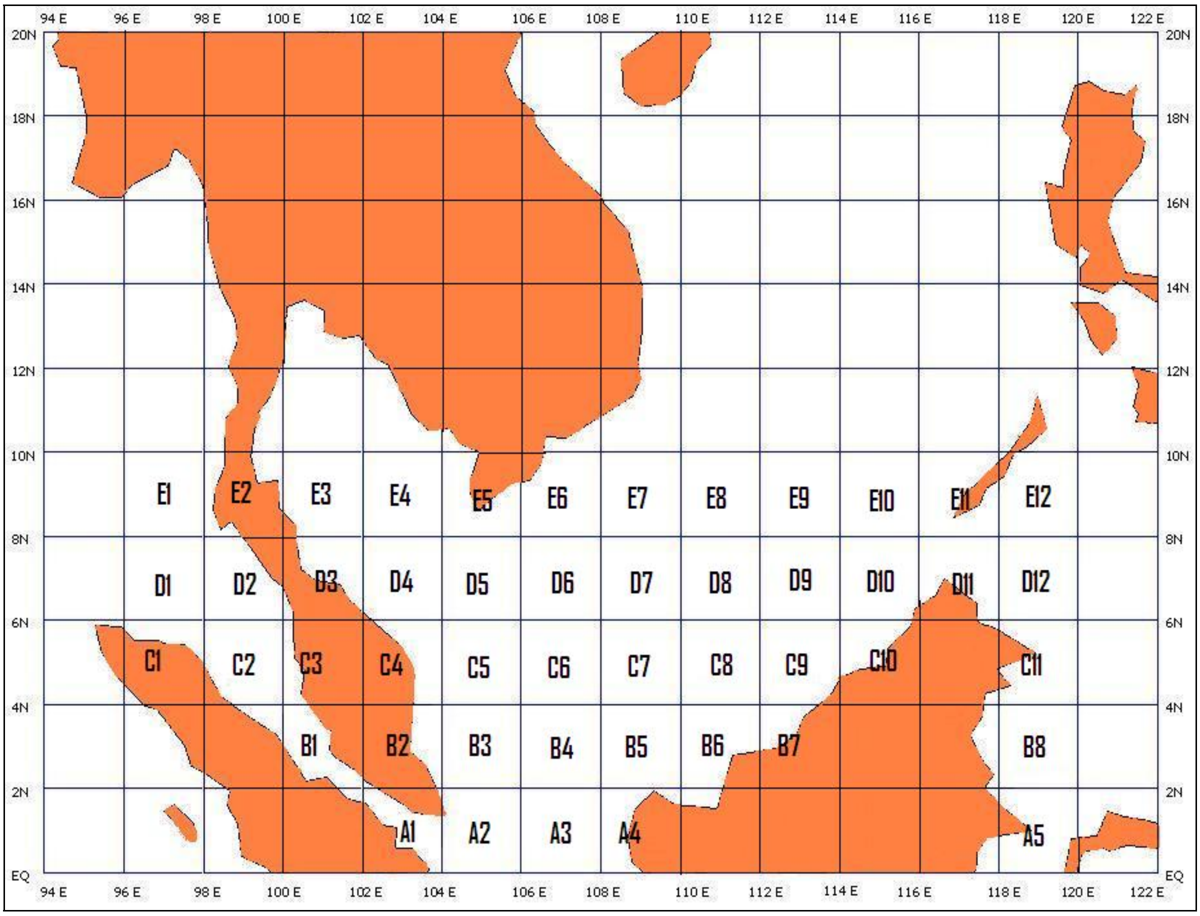


Figure 4.3: The 2º x 2º for latitude and longitude separation for Malaysia ocean area.

4.4 Calculating the Probability Distribution of Significant Wave Height

From these sorted data, the probability distribution of significant wave height *P(H)* will be calculated. The *P(H)* is simply to be calculated by totaling *P(H)* for every Malaysian ocean 2º x 2º areas. The significant wave height data from satellite altimeter is needed to be assumed as continuous variate, a relative frequency (*fi*) to a class (*Hi*) based on Global Wave Statistic (GWS). If the total frequency is set to *N,* the relative frequencies (*Pi*) (probability distributions) of the significant wave height are calculated as follows:

$$P_i = \frac{f_i}{N} \qquad \sum_i P_i = 1 \tag{4.1}$$

Where; *Pi* = probability of occurrence
fi = relative frequency to a class of 0.1 m
N = total frequency

The ultimate aim of this calculation is to observe the reliability and the accuracy of satellite wave height data compared to the local in-situ measurement. More than that, engineers need wave periods for their design calculation. However, satellite wave data do not provide wave period directly. Thus, there is a need to derive wave period value from other basic parameter of satellite data.

4.5 Derivation of the Wave Periods from Satellite Altimeter Data.

The derivation of wave periods from altimeter data is still in its early development (Carter et al., (1989); Davies et al., (1997)). Three approaches have been taken which are made by, Hwang et al, (1997a), Davies et al, (1998) and Gommengiger et al. (2003). However, these studies are in their early stages, and large scale verification is necessary before an altimeter wave period parameter reaches a suitable stage of maturity to enable its acceptance by the research community (Fu and Cazenave, 2001). All of these methods will be explained briefly in this section.

4.5.1 Hwang Method

Empirically, peak period of the wave field, T, is related to wind speed, U, and wave height, H, and is given by;

$$U/(gT) = 0.048(U^2/(gH))^{0.67} \tag{4.2}$$

where, *g* is the gravitational constant. Hwang reported that using the T/P data to derive U and H, the period calculated from (4.2) was found to be slightly less (by 6%) than the buoy measured peak period.

4.5.2 Davies Method

Relating the sigma0 value with the probability distribution of the sea surface slopes allows the variance of the slopes to be expressed in terms of the spatial spectral moments. Using the dispersion relationship these can be converted into the temporal spectral moments. As a result we can obtain an estimate of the fourth spectral moment, m_4, as a function of sigma0. Combining this with m_0, obtained from the significant wave height value, allows the altimeter to estimate wave period,

Ta. So, by analogy an altimeter wave period as equal to;

$$Ta = \left(\frac{m_0}{m_4} \right)^{1/4} \tag{4.3}$$

The algorithm was then modified to include an empirically determined dependence upon “pseudo wave age” (a wave age like parameter that can be derived from altimeter);

$$\text{Pseudo wave age, } \xi_a = 2.56. (H_s^2.g^2/U_{10}^4)^{0.3} \tag{4.4}$$

The final algorithm is two stage functions, the first stage calculates an altimeter period as function of significant wave height and radar backscatter, the second stage is quadratic function of this altimeter period and altimeter derived pseudo wave age (a function of significant wave height and wind speed).

$$T_z = a + bTa + c\zeta_a + dTa^2 + e\zeta_a^2 + fTa\zeta_a \tag{4.5}$$

Where;

a = 3.6231; b = 0.0754; c = 0.1943; d = -0.0188; e = 0.0000; f = 0.1991

Early tests suggested that the altimeter could provide a wave period estimate which was accurate to approximately 0.7s.

4.5.3 Gommengiger Method

This method uses the radar backscatter coefficient that is related under the Geometrical Optics approximation to the inverse of the mean square slope (mss) of the long ocean waves:

$$\sigma^0 \sim \frac{1}{mms} \tag{4.6}$$

In turn, ocean wave slope is dimensionally equivalent to the ratio of some measure of the ocean wave height and the ocean wavelength, L:

$$slope \sim \frac{SWH}{L} \tag{4.7}$$

The ocean wavelength is related to wave period, T and phase velocity, c, through L=cT. Under the deep-water approximation, the wave phase velocity is related to the ocean wave period through the dispersion relationship for gravity waves:

$$c = \frac{gT}{2\pi} \tag{4.8}$$

So that $L \sim T^2$

And

$$mss \sim \frac{SWH^2}{T^4} \tag{4.9}$$

and thus:

$$T \sim (\sigma^0 SWH^2)^{0.25} \tag{5.0}$$

From this, simple empirical model was built by performing a linear regression of wave period from buoy against this approximate T. Then the coefficients fitted using Orthogonal Distance Regression for linear models in log-log space of the form to derive zero up-crossing periods, T_z are;

$$Log_{10}(T_z) = 0.361 + 0.967 * Log_{10}(T) \tag{5.1}$$

4.6 Calculate the Joint Probability Distribution Function of Hs-Tz and Tabulate in Scatter Diagram Format

Generally, joint probability distribution function of H (significant wave height) and T (zero crossing wave periods) is given by:

$$P(H,T) = P(H)P(T|H) \qquad (5.2)$$

where; P (H): marginal probability distribution of wave height

$P(T|H)$: Conditional probability of wave period given the height H

The probability distribution for SWH from satellite data is seem a straight forward method but for the conditional probability of wave period given by the height H is quiet complicated method and still at the early stage of research. Wave data collection is generally of long-term benefit. Thus, the data should be banked in proper format, preferably with a central data bank such as the British Oceanographic Data Centre and above all it should be properly documented. In engineering design calculations of ships and offshore structures, wave data are used either in the form of statically data or converted into mathematical models.

In this research, the result for wave height data and wave height period from satellite altimeter observation will be tabulate in the form of joint Hs-Tz probability diagrams (scatter diagrams) which was developed by Hogben et al., (1986) as shown in Figure 2.1. Probability of occurrence of pairs of wave heights and wave periods will be presented in the form of bivariate Hs-Tz histogram which is also known as a scatter diagram. Each individual observation of Hs will be rounded to the nearest 0.5m and its associated Tz to the nearest 0.5s. The number of observations falling into each compartment on the chart is then calculated and divided by total number of observations to give the occurrence in part per thousand. These figures are rounded to the nearest whole number. Where the number of occurrences is less than 1 part per thousand, the actual number is given to allow better assessment of the probability of unusual conditions. The total number of observations should be quoted (Tucker, 1991).

4.7 Development of Computer Program

To automate the procedure, a computer program was written using Fortran 77. The flowchart is given in Figure 4.4 and the program code is given in Appendix D.

4.7.1 Program Overview

This program sorts the data based on latitude and longitude for the selected Malaysian ocean area. Then the program calculates the wave periods using the specific algorithm. The probability of occurrence of the pairs of wave heights and derived wave periods will be counted. And after that, the scatter diagram which is based on this joint probability of occurrence will be tabulated.

4.7.2 The algorithm of the Programme

1. Set the num of file k=0
2. Read the selected year ‘cyear’
3. Read the selected month ‘cmonth’
4. Read the selected area ‘clocation’
5. Identify the ‘cyear’ to the ‘years’
6. Identify the ‘cmonth’ to ‘month’
7. Identify the num of file ‘nflile’
8. Read the filename ‘filenm = number//month//years’
9. Open the file
10. Read the number of data (ndata) at the file header

11. Read the year, day, hr, minute, sec, y, Z, sig0, SWH, U
12. Assigning the location name based on y and Z values within 2^o x 2^o latitude and longitude using else if function
13. If area = location ; value (k) = value (I)
14. Add 1 to the number of file
15. Close the file
16. Print heading
17. Identify the ‘area’ to ‘location’
18. Print the data values
19. Save file
20. Compute wave period
21. Print the wave period values
22. Set count = 0
23. As long as there are data values ; add 1 to count
24. Divide the count by the total of data to get the probability
25. Print the scatter diagram
26. Save file
27. End

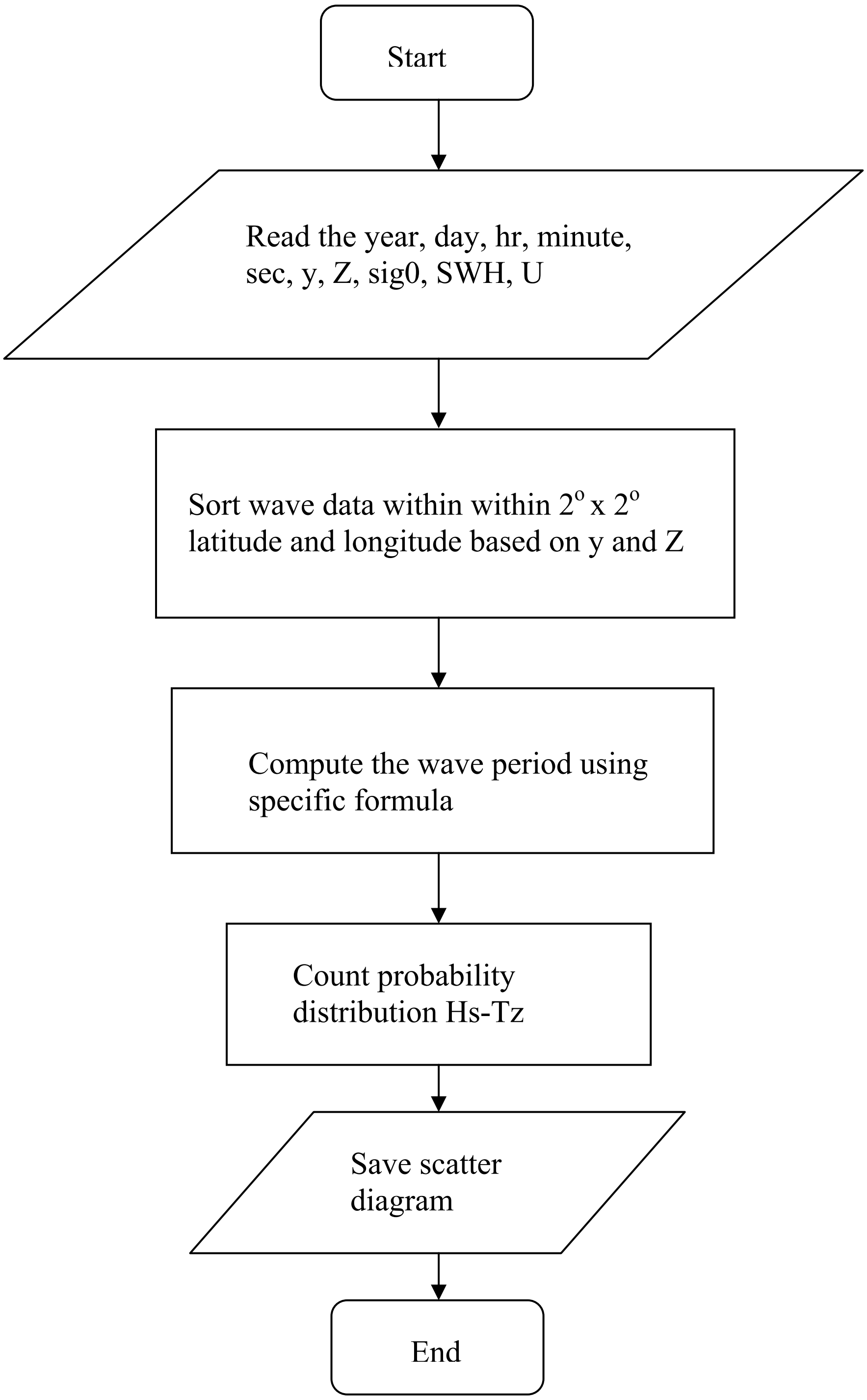


Figure 4.4: Flow chart for the computer program

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Introduction

The methods to derive probability of occurrence of wave periods and joint probability distribution of wave heights and periods are applied to a particular Malaysian sea area. The results will be compared with the respective wave data of Malaysia which is Monthly Summary of Marine Meteorological Observations (1997-2001) from Malaysian Meteorological Services (MMS) (1997) and also with Global Wave Statistic from British Maritime Technology (BMT) (1986). Another comparison was done with data from Petronas Research and Scientific Services Sdn. Bhd. (PRSS, 2005).

5.1.1 Validation of T/P with MMS

For comparison with MMS data, five boxes from grids of Figure 4.3 are chosen and these are shown in Figure 5.1. The boxes selected namely labeled as A2, B3, C5, D6 and E7. These areas are chosen because of the availability of adequate data from MMS for comparison with T/P. T/P data for year 1997-2001 are obtained and compared with MMS data for the same period.

5.1.2 Validation of T/P with GWS

GWS data covers the whole of South China Sea, Straits of Melaka and Gulf of Siam. Therefore for comparison with GWS data, the satellite data for the area bounded by the box will be used (see Figure 5.1).

5.1.3 Validation of T/P with PRSS

Petronas Research and Scientific Services Sdn. Bhd. (PRSS, 1981) provides measured sea surface data by wave radar measurement on the offshore oil and gas production platforms in the South China Sea at latitude of 6.4^{o}N and longitude of 104.0^{o} E. For comparison with this data, T/P data was selected within the gray colored boxes (see Figure 5.1) which is between the longitude of 104°E to 106°E and latitude 6°N to 8°N. The data was in period for year 1997-2000.

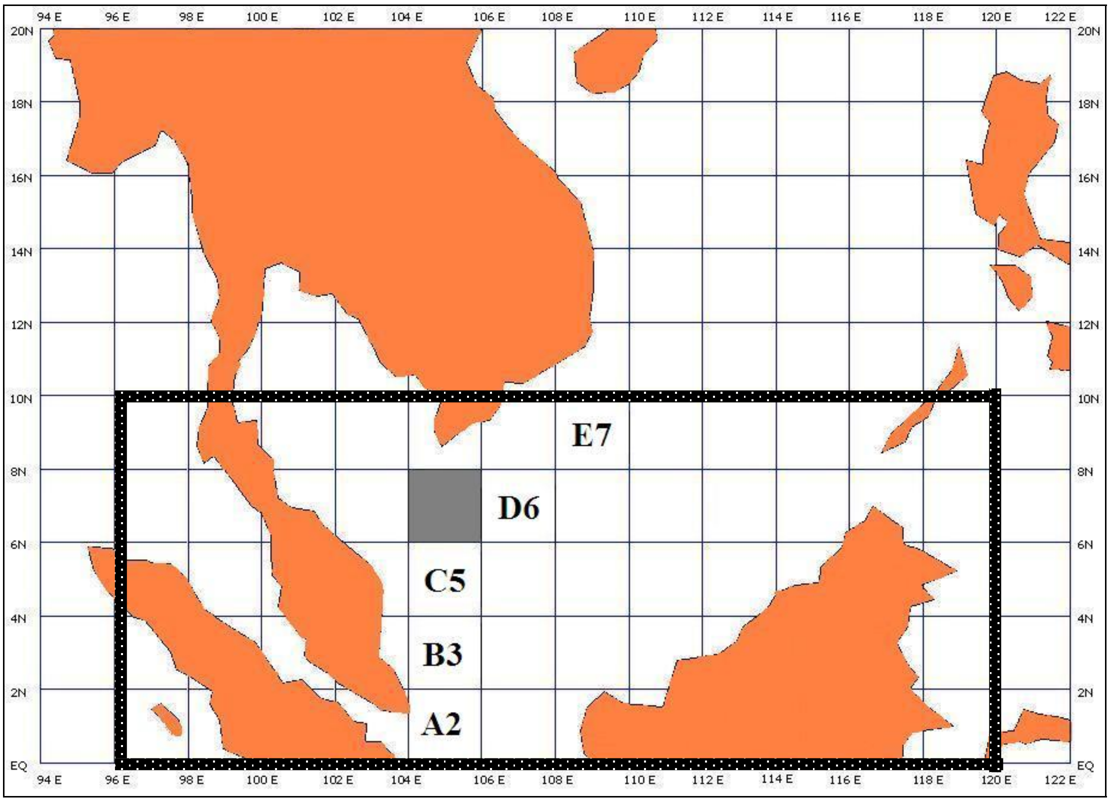


Figure 5.1: Location of selected area for comparison

5.2 Wave Heights Data

Results of wave height comparison data are given in following sections:

5.2.1 Comparison Between T/P and MMS

The comparison of 5 year (1997-2001) average wave heights from MMS and T/P is given in Table 5.1 and Figures 5.2 to 5.6 represents areas of A2, B3, C5, D6 and E7 respectively. It is shown that the T/P data agreed well with the data from MMS especially in A2, B3 and C5. For D6 and E7, T/P average wave heights seem higher then MMS data. The percentage column show only 19% from overall data had differences over 50% with another. The A2, B3 and C5 are in the main ship traffic lanes and thus unlike D6 and E7 they do not suffer due to inadequate wave data report. As been stated by Gonzalez et al. (1991), because visual data usually come from ship reports which are mainly on the main shipping routes; these data contains some shortcomings as discussed in section 2.4.

The T/P wave heights also show reasonable values based on the Malaysian wave climate which is influenced by the northeast monsoon (November-March) and the southwest monsoon season (June to September). As shown in Figures 5.2 to 5.6, during monsoon seasons which are in q01, q03 and q04, the T/P results are higher than MMS. This is related to the fact that voluntary data collected and reported were biased toward lower wave heights because more ships incorporates the effects of bad weather avoidance (Gonzalez et al., 1991; Soares, 1986).

Table 5.1: Comparison of average wave height from MMS and T/P for area A2, B3, C5, D6 and E7.

AREA		A2			B3			C5			D6			E7	
TEMPORAL	MMS	T/P	%	MMS	T/P	%	MMS	T/P	%	MMS	T/P	%	MMS	T/P	%
Q02-1997	0.4	0.69	29	0.8	0.73	7	1	0.79	21	0.8	0.9	10	0.95	1.14	19
Q03-1997	0.85	1.04	19	0.95	0.79	16	1.35	0.94	41	1	1	0	1.2	1.54	34
Q04-1997	0.77	0.92	15	1.15	1.41	26	1.23	1.62	39	1.17	1.7	53	1.27	1.96	69
Q01-1998	0.97	0.96	1	0.9	1.28	38	1.2	1.33	13	1	1.44	44	1.33	1.37	4
Q021998	0.93	0.72	21	0.73	0.85	12	1.03	0.88	15	0.87	0.94	7	0.97	1.19	22
Q03-1998	0.9	0.87	3	0.73	0.71	2	1.3	0.75	55	0.87	0.89	2	1.17	1.01	16
Q04-1998	0.77	0.89	12	0.9	1.45	55	1.47	1.54	7	0.97	1.77	80	1.37	2.19	82
Q01-1999	0.83	1.27	44	0.97	1.98	101	1.1	1.11	1	1.27	2.25	98	1.43	2.17	74
Q02-1999	0.57	0.53	4	0.6	0.53	7	0.93	0.61	32	0.83	0.78	5	1.1	1.08	2
Q03-1999	0.67	0.86	19	0.93	0.77	16	1.07	0.81	26	0.87	1.19	32	1.47	1.27	20
Q04-1999	1.03	0.95	8	1.33	1.12	21	1.3	1.19	11	1.6	1.83	23	1.6	2.23	63
Q01-2000	0.83	0.91	8	0.83	1.07	24	0.9	1.02	12	1.17	1.94	77	1.57	2.4	83
Q02-2000	1.17	0.66	51	0.6	0.59	1	0.87	0.63	24	0.87	0.51	36	0.9	0.84	6
Q03-2000	0.83	0.8	3	0.9	0.74	16	1.03	0.84	19	1	1.16	16	1.23	1.46	23
Q04-2000	0.67	0.73	6	0.87	1.18	31	1.27	1.29	2	1.2	1.39	19	1.43	1.9	47
Q01-2001	0.87	0.83	4	0.87	1.06	19	0.63	1.18	55	1.3	1.34	4	1.5	2.15	65
Q02-2001	0.77	0.48	29	0.57	0.58	1	0.57	0.61	4	0.77	0.72	5	1.1	0.92	18
Q03-2001	1.17	0.77	40	0.77	0.71	6	0.4	0.85	45	0.97	0.99	2	1.33	1.33	0
Q04-2001	0.67	0.88	21	0.93	1.59	66	1	1.67	67	0.67	1.64	97	2.17	2.17	0

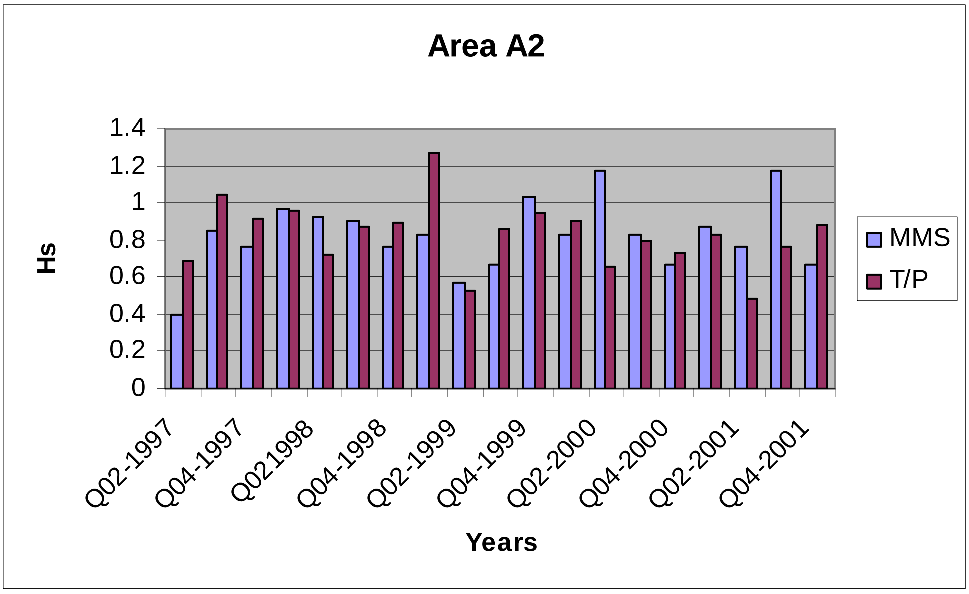


Figure 5.2: Comparison of average wave height from MMS and T/P for area A2.

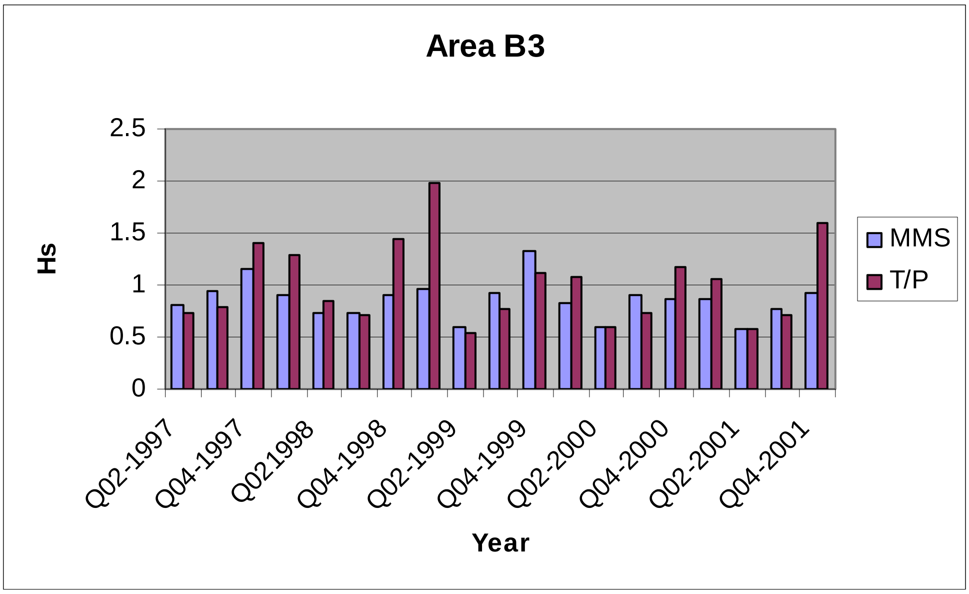


Figure 5.3: Comparison of average wave height from MMS and T/P for area B3.

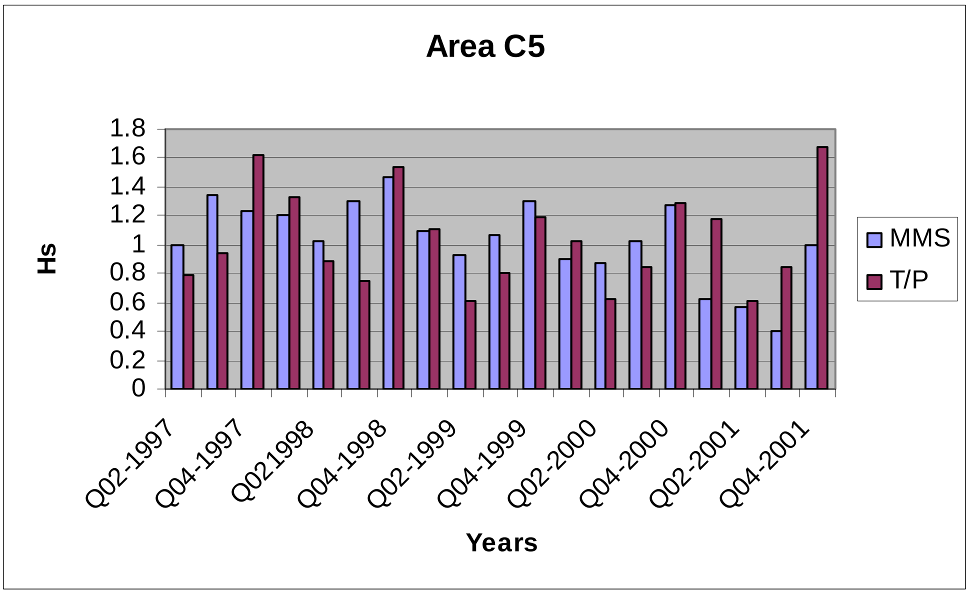


Figure 5.4: Comparison of average wave height from MMS and T/P for area C5.

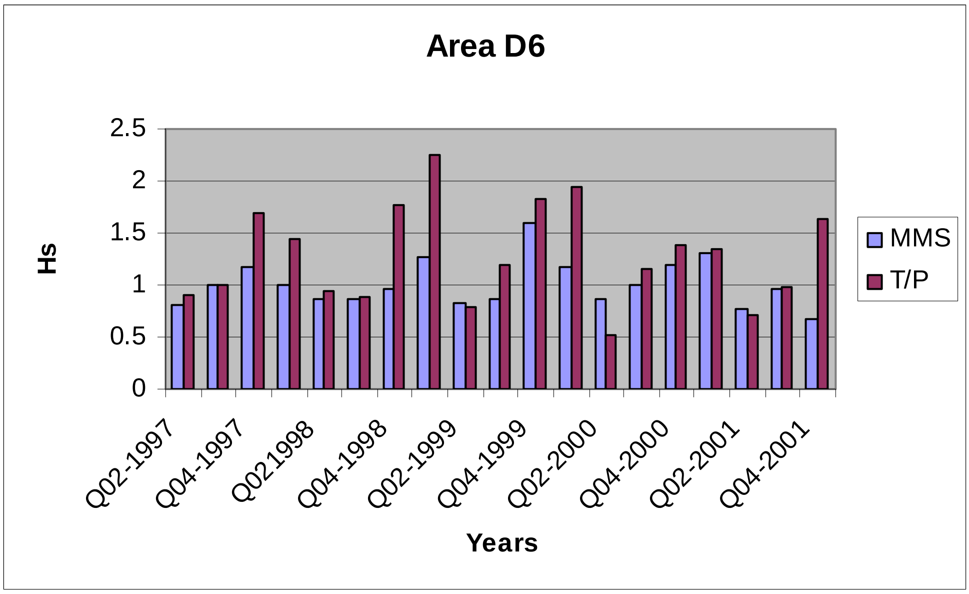


Figure 5.5: Comparison of average wave height from MMS and T/P for area D6.

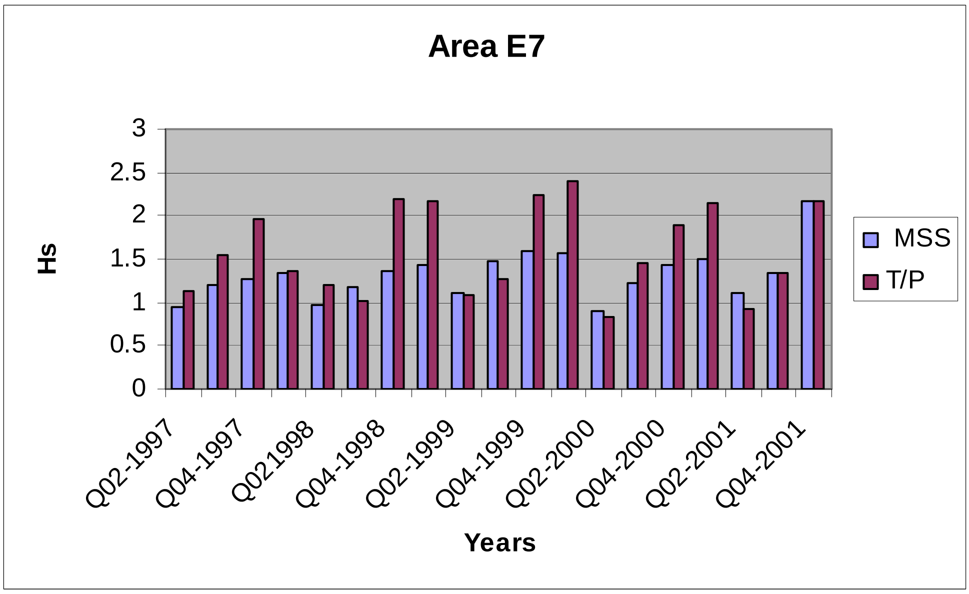


Figure 5.6: Comparison of average wave height from MMS and T/P for area E7.

5.2.2 Comparison Between T/P and GWS

Table 5.2 and Figure 5.7 showed the comparison of marginal probability of occurrence of wave heights between the T/P and Global Wave Statistic (GWS). The result shows the GWS probabilities are less in low wave heights, and the median being about 4.5m compared to 3m for T/P. It also indicates that the GWS data show a wider wave range than T/P.

Table 5.2: Comparison of marginal probability occurrence of wave height between T/P and GWS

Hs	T/P	GWS
0-1m	561	354
1-2m	346	385
2-3m	77	172
3-4m	15	60
4-5m	1	20
5-6m	0	7
6-7m	0	3
7-8m	0	1
8-9m	0	1
9-10m	0	0

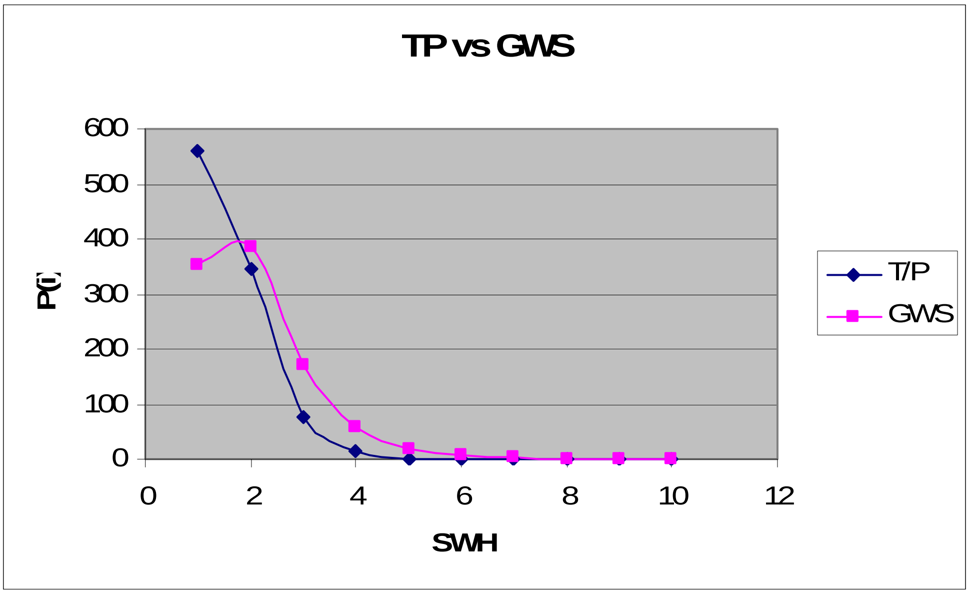


Figure 5.7: Comparison of marginal probability of occurrence of wave height between T/P and GWS

The probability of exceedance curve for each distribution is plotted in Figure 5.8. A 3-parameter Weibull function with the following equation is used to describe the distributions in the quantities values (Bitner-Gregesen and Cramer, 1994):

$$P(x \geq Hs) = \frac{\beta}{\alpha}\left[\frac{Hs-\gamma}{\alpha}\right]^{\beta-1} \exp\left[-\left(\frac{Hs-\gamma}{\alpha}\right)^{\beta}\right] \qquad (5.1)$$

where α, β and γ are the parameters defining the shape of the curve. By curve fitting methods, the parameters describing the GWS and T/P distributions in quantities values for this particular location. The result are obtained and given in Table 5.3.

Table 5.3: Weibull Parameters for Wave Height Exceedance Cumulative Probabilities

Parameter	α	β	γ
GWS	1	0.5	0.2
T/P	2.7	2	1.8

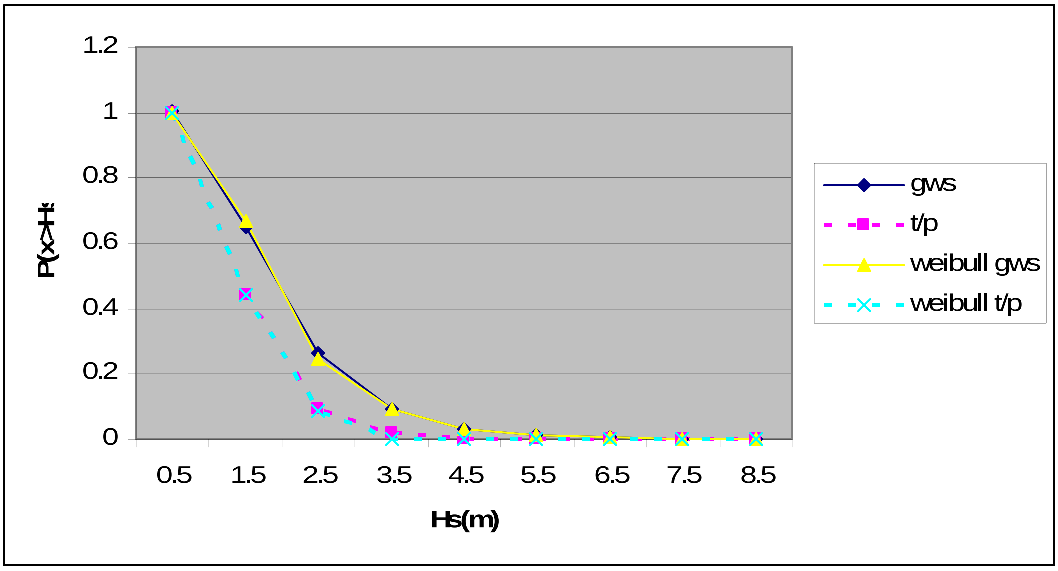


Figure 5.8: Probability distribution of wave exceedance

The results indicate that the data provided by T/P markedly different from that given by GWS. The shape of the probability exceedance curve shows that generally wave heights from T/P are lower at this selected area. According to Bitner-

Gregersen and Cramer (1994), for the considered locations, the GWS data both underestimate as well as overestimate significant wave height. Thus, the inconsistent trend in GWS data could lead to erroneous results for designing ocean structures in the selected area.

5.2.3 Comparison Between T/P and PRSS

The other comparison of 4-year marginal probability of occurrence of wave heights between T/P data and PRSS is given in Table 5.4 and Figure 5.9. The buoy data shows a preponderance of lower wave heights. This may due to apart from the different regularity between in-situ and satellite measurements, the measurement principles are also quite different (Park et al., 1993). The result also showed that both data was abundant in the same range which is 0 to 1m but significant for T/P in the range of 1 to 2m. Both data sets show that no waves are recorded beyond 4m wave heights in that area for period 1997-2000. This seems to agree with the result in section 5.2.2 where the maximum wave heights from T/P are in range of 4 to 5m. This again indicates that the accuracy of GWS data can be argued.

Table 5.4: Comparison of marginal probability occurrence of wave height between T/P and PRSS

Hs	PRSS	Topex
0-1m	0.72	0.51
1-2m	0.25	0.39
2-3m	0.03	0.10
3-4m	0.00	0.00
4-5m	0.00	0.00
5-6m	0.00	0.00
6-7m	0.00	0.00
7-8m	0.00	0.00
8-9m	0.00	0.00
9-10m	0.00	0.00

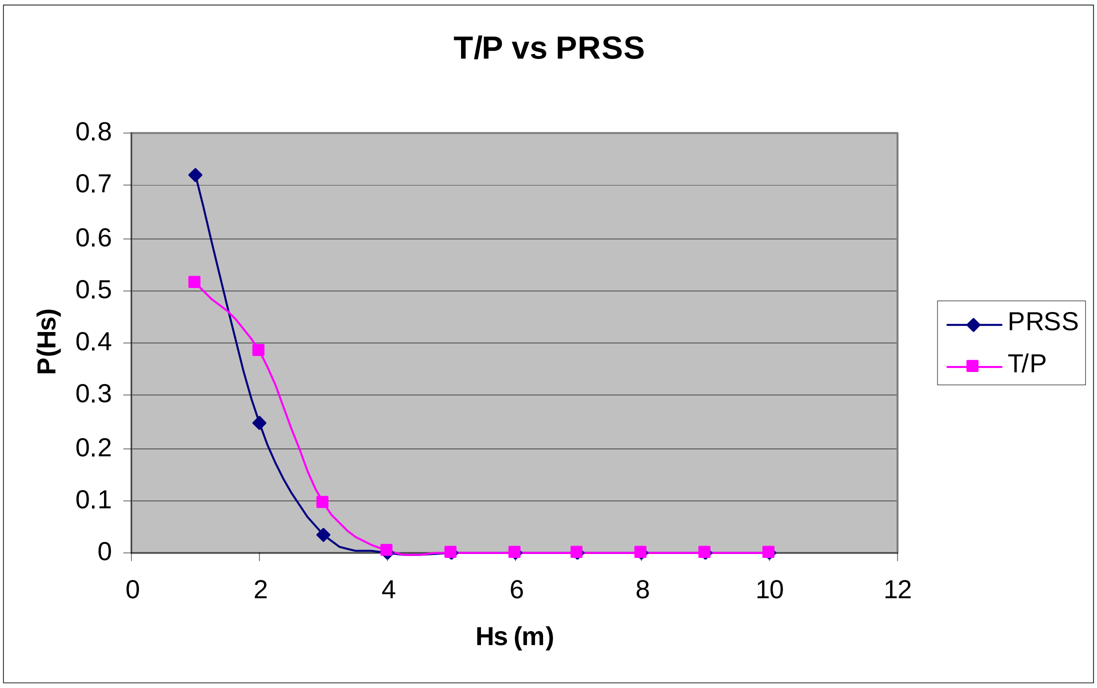


Figure 5.9: Comparison of marginal probability occurrence of wave height between T/P and PRSS

5.3 Derivation Satellite Wave Period Data

Derivations of wave periods from satellite wave data using three approaches have been described in section 4.5. Comparison made with buoy measured data from two sites; NDBC and PRSS.

5.3.1 Comparison Between T/P and NDBC

Prior to obtaining the PRSS data, the validation of wave period was done using data of other countries. This is due to inadequate in-situ data available for Malaysian sea. Therefore, comparison between T/P data and the buoy data from National Data Buoy Center (NDBC) was done for one site in the Florida Sea. The buoy was deployed between longitude 86°12′ W and latitude 28º47′N (see Figure 5.10). The data contain measured wave data for every hour everyday. The data not only contain wave heights but also wind speeds, average wave periods and wind direction. The data are available for free download from the main domain NDBC server (National Data Buoy Center Home Page). The comparison was made between this data with T/P within longitude 86ºW to 88ºW and latitude 28ºN to 30ºN for average of 4 year period 1997-2000.

Figure 5.10: Location of selected buoy-42039 (black box area)

Comparison with the NDBC buoy data had shown encouraging results. The result which is showed in Table 5.5 and Figure 5.11 indicates that the Hwang method seems to closely match with the buoy data. Although the values of probability peak period are quite far but it still in the same range which is between 4.5s to 5.5 s. On the other hand, the wave periods derived using Davies and Gommenginger methods were in the different range of peak probability which is 3.5s to 5s. It should be noted however, that the various methods use different types of wave periods. Gommenginger method and Davies method give zero-crossing periods, while Hwang method derives peak periods while buoy period data are given as mean wave period.

Table 5.5: Comparison of marginal probability occurrence of wave height from T/P data with NDBC buoys data.

T(sec)	NDBC	HWANG	GOMMEN	DAVIES
0-1	0.01	0.09	0.07	0.00
1-2	0.00	0.11	0.14	0.00
2-3	0.00	0.11	0.18	0.00
3-4	0.26	0.20	0.57	0.64
4-5	0.53	0.21	0.04	0.27
5-6	0.17	0.17	0.00	0.04
6-7	0.02	0.05	0.00	0.04
7-8	0.00	0.04	0.00	0.01
8-9	0.00	0.01	0.00	0.00
9-10	0.00	0.00	0.00	0.00
10-11	0.00	0.00	0.00	0.00
11-12	0.00	0.00	0.00	0.00
12-13	0.00	0.00	0.00	0.00

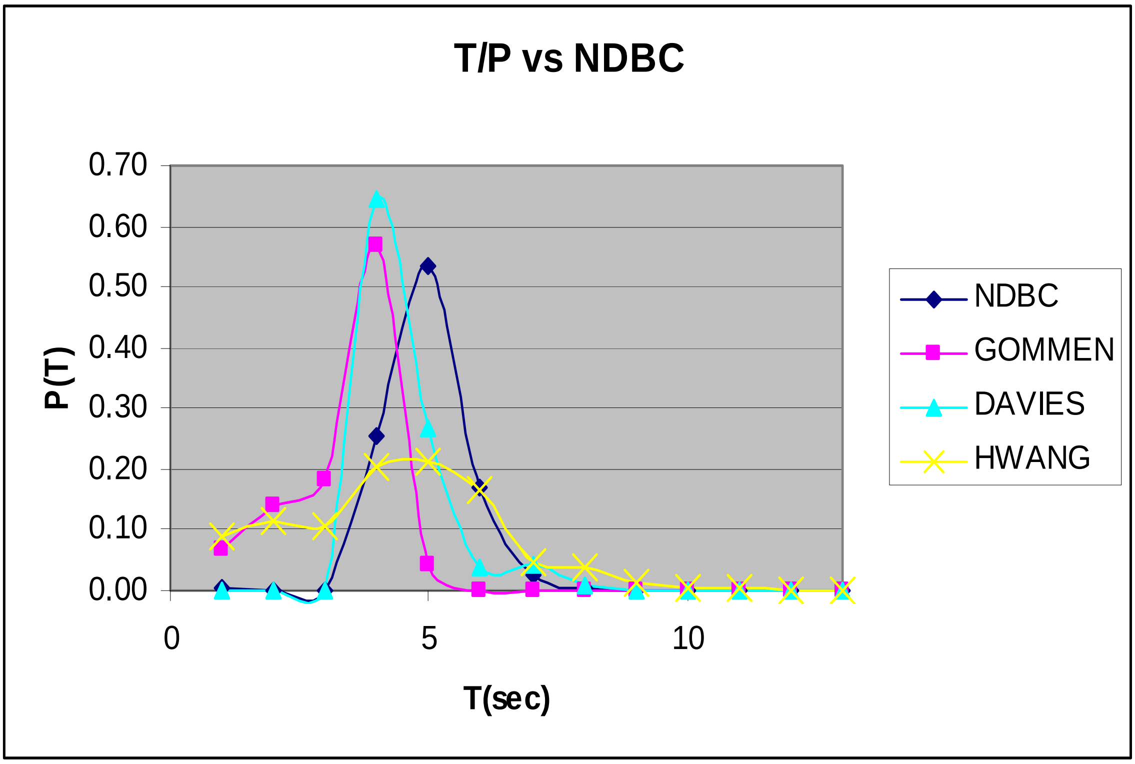


Figure 5.11: Comparison of marginal probability occurrence of wave period from T/P data with NDBC buoy data.

5.3.2 Joint Probability Data

Scatter diagrams representing the joint probability distributions of wave heights and periods are presented in Tables 5.6 to 5.9. The data are presented in a format similar to GWS as shown earlier in Table 4.4. Table 5.6 shows joint probability distributions for measured data from PRSS while the distributions for satellite data derived using the three methods are shown in Tables 5.7, 5.8 and 5.9 respectively.

It is quite difficult to see any resemblance or discern any pattern of similarities between the probability distributions obtained using the various methods.

To investigate just period distribution, comparison of marginal probability occurrence of wave periods from PRSS wave data with the marginal probability occurrence of wave periods derived using the various methods is given in Table 5.10. The data is plotted in Figure 5.12.

Figure 5.12 indicates that there seems to be a very close match between Hwang et al. method and the measured PRSS period distribution and also surprisingly with the GWS. The Davis et al. method and Gommengiger et al. method results show peak probabilities between 3 to 5 seconds while Hwang, PRSS and GWS indicate peak probabilities around 6 seconds. In addition, unlike others, Hwang and PRSS show there are appreciable occurrences of wave periods between 6 to 9 seconds. It should be noted again however, that the various methods use different types of wave periods. PRSS data and Hwang method data are given as peak periods while Gommengiger, Davis and GWS derive zero-crossing periods. It can be concluded that the Hwang method show the best fit when compared it to in situ measurement from PRSS and NDBC.

Table 5.6: PRSS Measured data

SIGNIFICANT WAVE HEIGHT

TOTAL	112	267	282	183	122	31	2	1	1	0	0	1000
>14												
13-14												
12-13												
11-12												
10-11												
9-10												
8-9												
7-8												
6-7												
5-6												
4-5												
3-4												1
2-3				1	12	21						34
1-2		13	42	89	94	8						246
0-1	112	254	240	94	16	1	1	1	1			718
		4-5		6-7		8-9		10-11	~	12-13	~	TOTAL
	<4		5-6		7-8		9-10		11-12		>13	

PEAK PERIOD (s)

Table 5.7: Davies Method

SIGNIFICANT WAVE HEIGHT

TOTAL	618	314	38	27	1	1	1					1000
>14												
13-14												
12-13												
11-12												
10-11												
9-10												
8-9												
7-8												
6-7												
5-6												
4-5		2										2
3-4		3										4
2-3	75	21										96
1-2	294	83	4	1	1	1	1					385
0-1	249	205	34	26								514
		4-5		6-7		8-9		10-11	~	12-13	~	TOTAL
	<4		5-6		7-8		9-10		11-12		>13	

ZERO CROSSING PERIOD (s)

Table 5.8: Gommenginger Method

SIGNIFICANT WAVE HEIGHT	<4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	~ 11-12	12-13	~ >13	TOTAL
TOTAL	465	290	186	53	5	1						1000
>14												
13-14												
12-13												
11-12												
10-11												
9-10												
8-9												
7-8												
6-7												
5-6												
4-5					2							2
3-4				1	3							4
2-3			44	52								96
1-2	1	241	141	1								384
0-1	464	49										513

ZERO CROSSING PERIOD (s)

Table 5.9: Hwang Method

SIGNIFICANT WAVE HEIGHT	<4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	~ 11-12	12-13	~ >13	TOTAL
TOTAL	61	232	248	229	154	52	17	5	2			1000
>14												
13-14												
12-13												
11-12												
10-11												
9-10												
8-9												
7-8												
6-7												
5-6												
4-5							1	1				2
3-4						1	2					4
2-3				6	58	28	4					96
1-2	3	9	109	181	66	10	3	1	2			384
0-1	58	223	138	43	30	14	6	2				515

PEAK PERIOD (s)

Table 5.10: Comparison of marginal probability occurrence of wave period between T/P, PRSS and GWS data for area 6°N-8°N, 106°E -108°E.

Tz (sec)	PRSS	Davies	Hwang	Gommen	GWS
0-1	0.00	0.00	0.00	0.00	0.00
1-2	0.00	0.00	0.00	0.00	0.00
2-3	0.00	0.00	0.01	0.07	0.00
3-4	0.11	0.51	0.05	0.39	0.08
4-5	0.27	0.41	0.23	0.29	0.28
5-6	0.28	0.04	0.25	0.19	0.34
6-7	0.18	0.03	0.23	0.05	0.20
7-8	0.12	0.01	0.15	0.00	0.07
8-9	0.03	0.00	0.05	0.00	0.02
9-10	0.00	0.00	0.02	0.00	0.00
10-11	0.00	0.00	0.00	0.00	0.00
11-12	0.00	0.00	0.00	0.00	0.00
12-13	0.00	0.00	0.00	0.00	0.00

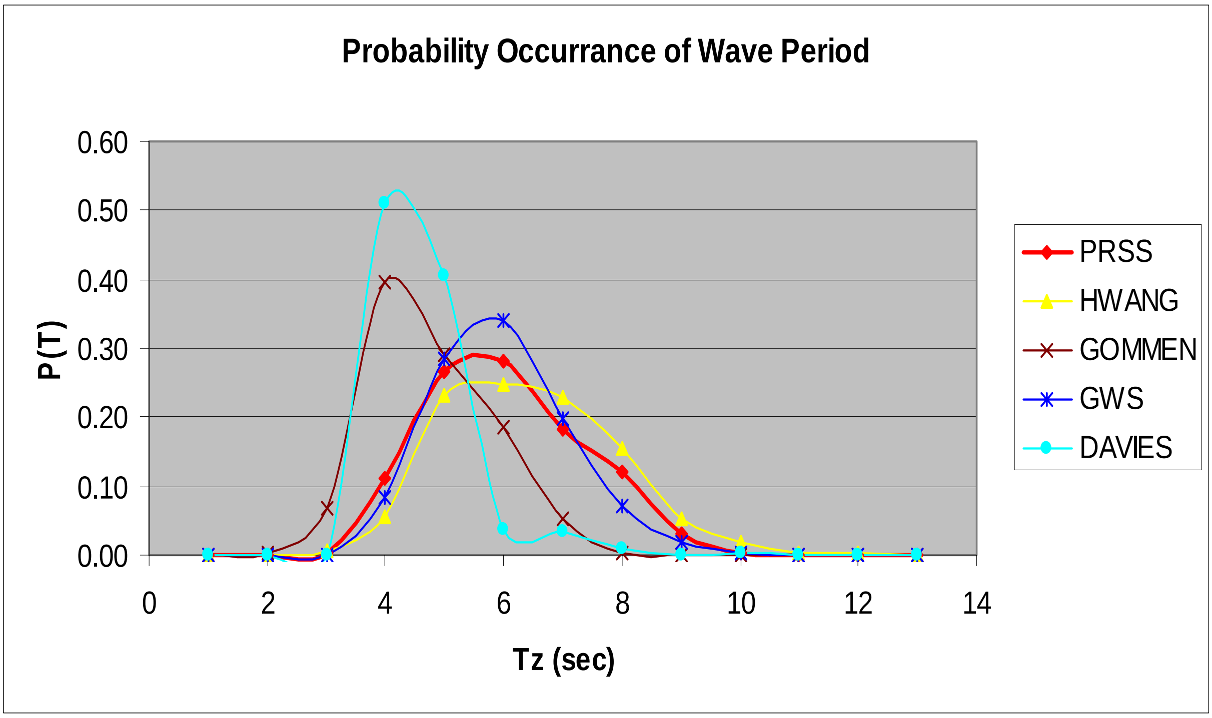


Figure 5.12: Comparison of marginal probability occurrence of wave period between T/P, PRSS and GWS data for area 6°N-8°N, 106°E -108°E.

5.4 Overall Discussion

Although the wave height data was enough to use in preliminary stage of ship design, but the important of wave period cannot be neglected. According to Soares (1986), the average period of the sea state is an important parameter governing the response of ocean structures to wave excitation. However the calibration of the wave periods is difficult because of fewer studies are available and a lack of correlation between the observed and the measured periods. It is also due to the lower quality of wave period data. Furthermore, the existing analyses adopt different definitions of period, complicating the comparisons between results (Soares, 1986).

As been shown in the result earlier the difficulties to make the comparison with the same type of wave period due to the lack of the in situ data can cause the unfair comparison. However, when the same type of in situ data compared with the same type of derived wave period from satellite, they showed the encouraging result in Figures 5.11 and 5.12. This research can conclude that the Hwang method provides the best fit for Malaysian ocean wave data. This is supported by Carter et al. (1989) that in regions of low swell effects, the combination of wind speed and wave height further yields the information of wave period which is similar with the equation that is used by Hwang.

The other reason for this conclusion was based on the advantage and disadvantage of the approach that is suggested by respective researchers. For example, the Davies method always gives the values for the wave period although the wave period that measured from satellite was zero. This happened because the value for one coefficient to derive the wave period does not relied on any values from the satellite parameter and this coefficient give the minimum value for wave period from satellite. On the other hand, Gommenginger et al. (2003) mentioned in their paper that their method was better suited to wind-sea conditions than to swell conditions which is different from our sea conditions. As reported by Omar and Adi (2001), the measured data from Malaysian sea seemed to emanate from a compromise of wind-driven sea waves and low frequency swell. Therefore using the Gommenginger method can lead to the error in derivation.

Another aspect to consider is on the use of coefficients in Davies and Gommenginger methods. The lack of the in situ data not only causes the limitation in comparison but also hinder the process of deriving suitable coefficients for areas considered. When using the coefficients derived from other locations, it can cause error in the calculation and its accuracy is debatable.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

Currently, the only available wave data sources at Malaysia are the Monthly Summary of Malaysian Meteorological Observation from Malaysian Meteorological Services (MMS) and Global Wave Statistic (GWS) from British Maritime Technology Ltd (BMT). These two sources are the main reference for the marine technologists such as naval architects, ship designers, coastal and offshore engineers to get the information on wave data such as wave height, wave period and wind speed for use in their line of work. These sources were based on the visual observations from the volunteering ships, the accuracy of which sometimes questionable. Nevertheless, because of the lack of sources, they have to rely on these for their calculation, but they are aware of the limitation and accuracy. Thus, a new effort to collect wave data for Malaysian ocean must be made.

Ocean wave measurements from satellite are dramatically changing our way of obtaining ocean wave data for engineering purposes. The comparison with the various data sources has shown that more comprehensive data can be obtained for all sea areas using satellite altimetry technique. Comparison with presently available data based on visual observation has shown encouraging results in term of wave height data, but when compared with in situ measurement there is a slight over estimate on wave heights. This may arise from the different regularity between in-situ and satellite measurements, as well as the differences in the measurement principles.

This project has shown that the data provided by TOPEX/Poseidon satellite can be used to derive wave periods, which can then be used to obtain joint probability distribution of wave heights and periods. Three methods to derive wave periods have been described and their implementation on a particular Malaysian sea area has been presented. The results indicate that the Hwang method produces similar trends with the local data especially when compared with the PRSS data and also with the NDBC buoy data located in the Florida sea area.

The procedure to derive Malaysian ocean wave database based on satellite altimetry was clearly described in Chapter 4. It involves designing an algorithm to process and analyse the data after downloading the data from internet. The algorithm then sorts the data, calculates the joint probability distribution of wave height and wave period and lastly tabulates it in the scatter diagram format. Note that the wave period from satellite data for Malaysian ocean was best derived using Hwang method.

The present 2^o x 2^o grids used in this study is based on MMS (1996). This is equivalent to120 x 120 nautical miles. With such a small grids tedious work has to be done and data is limited due to small number of repeat visit of the satellite. For future work, it is proposed that larger grids are used to divide the Malaysian sea area. For example, the 13 marine regions delineated by Malaysian Meteorological Services such as Condore, Phuket, Bunguran etc. can be used as basis for such division. This can reduce the burden of work. Moreover more revisit of satellite can be obtained leading to more data for that particular area.

For comparison and validation purposes it is important to obtain in-situ zero crossing periods for selected sea areas. These in-situ data can be used in determining the coefficient more accurately for Davies and Gommenginger methods. With that information a better method to derive wave period can be developed then allowing a fair comparison to be made.

A development using web-based wave database is also recommended for future work. A number of examples on this matter have been described in Chapter 3. This web-based approach allows easy access to satellite-based database thus providing immense benefits to the maritime users and for ocean engineering applications.

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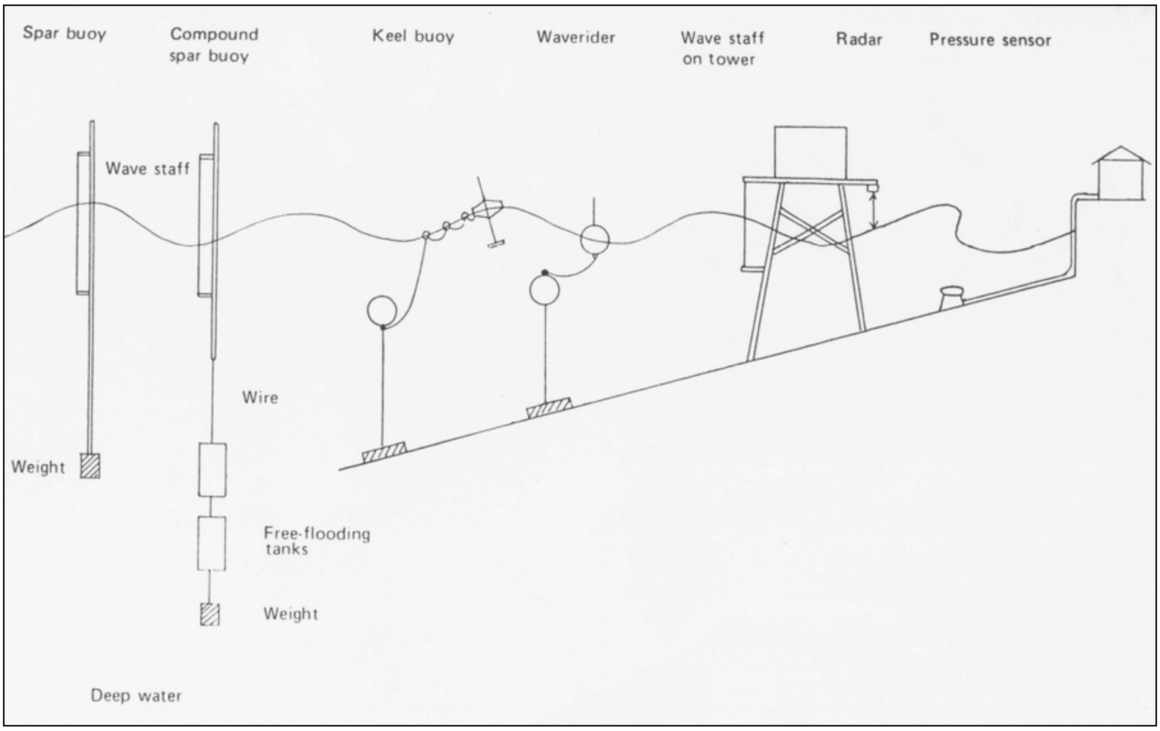
APPENDIX A

Method	Advantages	Disadvantages
1. Wave staffs	In situ measurement-most accurate ways	Need to be mounted well away from any sizeable structural members
2. Sub-surface sensors	In situ measurement-most accurate ways	i. Data being lost before it detected because it snag with the former data ii. Cable route must avoid areas where trawlers operate or ships anchor
3. Buoy	Results not influenced by proximity of structure	Limited number of deployment for vast area
4. Shipborne wave recorder	Capable recording waves on deep sea during a storm	Relation to the distribution of pressure on the hull and satisfactory theoritical treatment has not been found.
5. Visual observation	Basis of a worldwide of wave statistics	The probability of wave height to be smaller because ships try to avoid the storm seas.
6. Wave forecasting	Cover much wider sea areas and do not miss storms	Limited power of computers and lack of adequate understanding of wave generation process.
7. Direct remote sensors (i.e altimetry)	Interpretation of results is starightforward	A method to derived wave period is still in early stage.
8. Indirect remote sensors (i.e SAR)	Produces images with very high resolution	Greatly complicated in interpretation

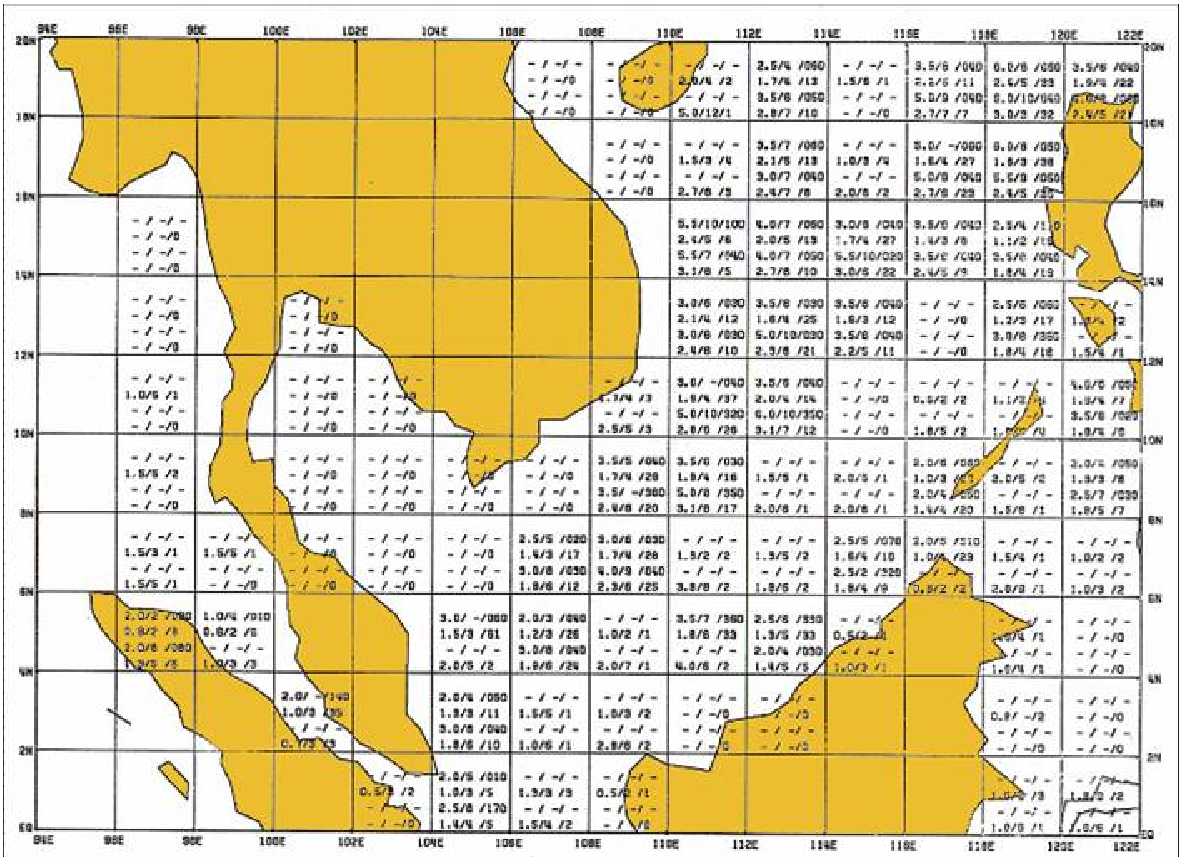
Appendix A: Advantages and disadvantages among the wave measurement methods.

APPENDIX B



Appendix B: Several method for wave measurement (Tucker, 1991)

APPENDIX C



Appendix C: Example of Monthly Summary of Marine Meteorological Observation, 1996 from MMS

APPENDIX D

```
      PROGRAM SORTWAVE
c     This program will sort wave data
c     from satellite measurement based on 2*2 degree

      parameter (Maxdata=20000)
      integer cyear,cmonth,nfile,clocation
      integer I,ndata,num,stoper(20000),area(maxdata)
      integer year(maxdata),day(maxdata),hr(maxdata),minute(maxdata)
      integer Y(maxdata),Z(maxdata),sig(maxdata),SWH(maxdata)
      integer syear(maxdata),sday(maxdata),shr(maxdata)
      integer sminute(maxdata),sy(maxdata),sz(maxdata)
      integer ssig(maxdata),sswh(maxdata),sarea(maxdata),k
      integer count1,count2,count3,count4,count5,count6,count7
      integer count8,count9,count10,count11,count12,count13,count14
      integer count15,count16,count17,count18,count19,count20,count21
      integer count22,count23,count24,count25,count26,count27,count28
      integer count29,count30,count31,count32,count33,count34,count35
      integer count36,count37,count38,count39,count40,count41,count42
      integer count43,count44,count45,count46,count47,count48,count49
      integer count50,count51,count52,count53,count54,count55,count56
      integer count57,count58,count59,count60,count61,count62,count63
      integer count64,count65,count66,count67,count68,count69,count70
      integer count71,count72,count73,count74,count75,count76,count77
      integer count78,count79,count80,count81,count82,count83,count84
      integer count85,count86,count87,count88,count89,count90,count91
      integer count92,count93,count94,count95,count96,count97,count98
      integer count99,count100,count101,count102,count103,count104
      integer count105,count106,count107,count108,count109,count110
      integer count111,count112,count113,count114,count115,count116
      integer count117,count118,count119,count120,count121,count122
      integer count123,count124,count125,count126,count127,count128
      integer count129,count130,qi130
      integer coun1,coun2,coun3,coun4,coun5,coun6,coun7
      integer coun8,coun9,coun10,coun11,coun12,coun13,coun14
      integer coun15,coun16,coun17,coun18,coun19,coun20,coun21
      integer coun22,coun23,coun24,coun25,coun26,coun27,coun28
      integer coun29,coun30,coun31,coun32,coun33,coun34,coun35
      integer coun36,coun37,coun38,coun39,coun40,coun41,coun42
      integer coun43,coun44,coun45,coun46,coun47,coun48,coun49
      integer coun50,coun51,coun52,coun53,coun54,coun55,coun56
      integer coun57,coun58,coun59,coun60,coun61,coun62,coun63
      integer coun64,coun65,coun66,coun67,coun68,coun69,coun70
      integer coun71,coun72,coun73,coun74,coun75,coun76,coun77
      integer coun78,coun79,coun80,coun81,coun82,coun83,coun84
      integer coun85,coun86,coun87,coun88,coun89,coun90,coun91
      integer coun92,coun93,coun94,coun95,coun96,coun97,coun98
      integer coun99,coun100,coun101,coun102,coun103,coun104
      integer coun105,coun106,coun107,coun108,coun109,coun110
      integer coun111,coun112,coun113,coun114,coun115,coun116
      integer coun117,coun118,coun119,coun120,coun121,coun122
      integer coun123,coun124,coun125,coun126,coun127,coun128
      integer coun129,coun130,q130
      integer counn1,counn2,counn3,counn4,counn5,counn6,counn7
      integer counn8,counn9,counn10,counn11,counn12,counn13,counn14
      integer counn15,counn16,counn17,counn18,counn19,counn20,counn21
      integer counn22,counn23,counn24,counn25,counn26,counn27,counn28
      integer counn29,counn30,counn31,counn32,counn33,counn34,counn35
      integer counn36,counn37,counn38,counn39,counn40,counn41,counn42
      integer counn43,counn44,counn45,counn46,counn47,counn48,counn49
      integer counn50,counn51,counn52,counn53,counn54,counn55,counn56
      integer counn57,counn58,counn59,counn60,counn61,counn62,counn63
      integer counn64,counn65,counn66,counn67,counn68,counn69,counn70
      integer counn71,counn72,counn73,counn74,counn75,counn76,counn77
      integer counn78,counn79,counn80,counn81,counn82,counn83,counn84
      integer counn85,counn86,counn87,counn88,counn89,counn90,counn91
      integer counn92,counn93,counn94,counn95,counn96,counn97,counn98
      integer counn99,counn100,counn101,counn102,counn103,counn104
      integer counn105,counn106,counn107,counn108,counn109,counn110
      integer counn111,counn112,counn113,counn114,counn115,counn116
      integer counn117,counn118,counn119,counn120,counn121,counn122
```

```
integer counn123,counn124,counn125,counn126,counn127,counn128
integer counn129,counn130,qu130
integer qi1,qi2,qi3,qi4,qi5,qi6,qi7,qi8,qi9,qi10,qi11,qi12,qi13
integer qi14,qi15,qi16,qi17,qi18,qi19,qi20,qi21,qi22,qi23,qi24
integer qi25,qi26,qi27,qi28,qi29,qi30,qi31,qi32,qi33,qi34,qi35
integer qi36,qi37,qi38,qi39,qi40,qi41,qi42,qi43,qi44,qi45,qi46
integer qi47,qi48,qi49,qi50,qi51,qi52,qi53,qi54,qi55,qi56,qi57
integer qi58,qi59,qi60,qi61,qi62,qi63,qi64,qi65,qi66,qi67,qi68
integer qi69,qi70,qi71,qi72,qi73,qi74,qi75,qi76,qi77,qi78,qi79
integer qi80,qi81,qi82,qi83,qi84,qi85,qi86,qi87,qi88,qi89,qi90
integer qi91,qi92,qi93,qi94,qi95,qi96,qi97,qi98,qi99,qi100,qi101
integer qi102,qi103,qi104,qi105,qi106,qi107,qi108,qi109,qi110
integer qi112,qi113,qi114,qi115,qi116,qi117,qi118,qi119,qi120
integer qi121,qi122,qi123,qi124,qi125,qi126,qi127,qi128,qi129
integer q1,q2,q3,q4,q5,q6,q7,q8,q9,q10,q11,q12,q13
integer q14,q15,q16,q17,q18,q19,q20,q21,q22,q23,q24
integer q25,q26,q27,q28,q29,q30,q31,q32,q33,q34,q35
integer q36,q37,q38,q39,q40,q41,q42,q43,q44,q45,q46
integer q47,q48,q49,q50,q51,q52,q53,q54,q55,q56,q57
integer q58,q59,q60,q61,q62,q63,q64,q65,q66,q67,q68
integer q69,q70,q71,q72,q73,q74,q75,q76,q77,q78,q79
integer q80,q81,q82,q83,q84,q85,q86,q87,q88,q89,q90
integer q91,q92,q93,q94,q95,q96,q97,q98,q99,q100,q101
integer q102,q103,q104,q105,q106,q107,q108,q109,q110
integer q112,q113,q114,q115,q116,q117,q118,q119,q120
integer q121,q122,q123,q124,q125,q126,q127,q128,q129
integer qu1,qu2,qu3,qu4,qu5,qu6,qu7,qu8,qu9,qu10,qu11,qu12,qu13
integer qu14,qu15,qu16,qu17,qu18,qu19,qu20,qu21,qu22,qu23,qu24
integer qu25,qu26,qu27,qu28,qu29,qu30,qu31,qu32,qu33,qu34,qu35
integer qu36,qu37,qu38,qu39,qu40,qu41,qu42,qu43,qu44,qu45,qu46
integer qu47,qu48,qu49,qu50,qu51,qu52,qu53,qu54,qu55,qu56,qu57
integer qu58,qu59,qu60,qu61,qu62,qu63,qu64,qu65,qu66,qu67,qu68
integer qu69,qu70,qu71,qu72,qu73,qu74,qu75,qu76,qu77,qu78,qu79
integer qu80,qu81,qu82,qu83,qu84,qu85,qu86,qu87,qu88,qu89,qu90
integer qu91,qu92,qu93,qu94,qu95,qu96,qu97,qu98,qu99,qu100,qu101
integer qu102,qu103,qu104,qu105,qu106,qu107,qu108,qu109,qu110
integer qu112,qu113,qu114,qu115,qu116,qu117,qu118,qu119,qu120
integer qu121,qu122,qu123,qu124,qu125,qu126,qu127,qu128,qu129
real pi1,pi2,pi3,pi4,pi5,pi6,pi7,pi8,pi9,pi10,pi11
real pi12,pi13,pi14,pi15,pi16,pi17,pi18,pi19,pi20,pi21
real pi22,pi23,pi24,pi25,pi26,pi27,pi28,pi29,pi30,pi31
real pi32,pi33,pi34,pi35,pi36,pi37,pi38,pi39,pi40,pi41
real pi42,pi43,pi44,pi45,pi46,pi47,pi48,pi49,pi50,pi51
real pi52,pi53,pi54,pi55,pi56,pi57,pi58,pi59,pi60,pi61
real pi62,pi63,pi64,pi65,pi66,pi67,pi68,pi69,pi70,pi71
real pi72,pi73,pi74,pi75,pi76,pi77,pi78,pi79,pi80,pi81
real pi82,pi83,pi84,pi85,pi86,pi87,pi88,pi89,pi90,pi91
real pi92,pi93,pi94,pi95,pi96,pi97,pi98,pi99,pi100,pi101
real pi102,pi103,pi104,pi105,pi106,pi107,pi108,pi109,pi110,pi111
real pi112,pi113,pi114,pi115,pi116,pi117,pi118,pi119,pi120,pi121
real pi122,pi123,pi124,pi125,pi126,pi127,pi128,pi129,pi130
real p1,p2,p3,p4,p5,p6,p7,p8,p9,p10,p11
real p12,p13,p14,p15,p16,p17,p18,p19,p20,p21
real p22,p23,p24,p25,p26,p27,p28,p29,p30,p31
real p32,p33,p34,p35,p36,p37,p38,p39,p40,p41
real p42,p43,p44,p45,p46,p47,p48,p49,p50,p51
real p52,p53,p54,p55,p56,p57,p58,p59,p60,p61
real p62,p63,p64,p65,p66,p67,p68,p69,p70,p71
real p72,p73,p74,p75,p76,p77,p78,p79,p80,p81
real p82,p83,p84,p85,p86,p87,p88,p89,p90,p91
real p92,p93,p94,p95,p96,p97,p98,p99,p100,p101
real p102,p103,p104,p105,p106,p107,p108,p109,p110,p111
real p112,p113,p114,p115,p116,p117,p118,p119,p120,p121
real p122,p123,p124,p125,p126,p127,p128,p129,p130
real pu1,pu2,pu3,pu4,pu5,pu6,pu7,pu8,pu9,pu10,pu11
real pu12,pu13,pu14,pu15,pu16,pu17,pu18,pu19,pu20,pu21
real pu22,pu23,pu24,pu25,pu26,pu27,pu28,pu29,pu30,pu31
real pu32,pu33,pu34,pu35,pu36,pu37,pu38,pu39,pu40,pu41
real pu42,pu43,pu44,pu45,pu46,pu47,pu48,pu49,pu50,pu51
real pu52,pu53,pu54,pu55,pu56,pu57,pu58,pu59,pu60,pu61
real pu62,pu63,pu64,pu65,pu66,pu67,pu68,pu69,pu70,pu71
real pu72,pu73,pu74,pu75,pu76,pu77,pu78,pu79,pu80,pu81
real pu82,pu83,pu84,pu85,pu86,pu87,pu88,pu89,pu90,pu91
real pu92,pu93,pu94,pu95,pu96,pu97,pu98,pu99,pu100,pu101
real pu102,pu103,pu104,pu105,pu106,pu107,pu108,pu109,pu110,pu111
real pu112,pu113,pu114,pu115,pu116,pu117,pu118,pu119,pu120,pu121
```

```
      real pu122,pu123,pu124,pu125,pu126,pu127,pu128,pu129,pu130
      real sec(maxdata),ssec(maxdata),U(maxdata),su(maxdata)
      real sTP(maxdata),Ta(maxdata),Wa(maxdata),Tz1(maxdata),Mo(maxdata)
      real T1(maxdata),T2(maxdata),sTP1(maxdata),B(maxdata)
      real sTP2(maxdata)
      character*3 month,number,bil
      character*4 years
      character*10 filenm
      character*3 name
      character*18 loc
      character*25 savefilenm,saveprodis,saveprodisi,saveprodissi
c      character*1 saveras,newlocation


      k=1
C      SELECTING FILES AND AREA
      print*,'Select year: 1-8'
      print*,'  1:1997   2:1998   3:1999'
      print*,'  4:2000   5:2001   6:2002'
      print*,'  7:2003'
      read*,cyear
       print*,'Select month: 1-4'
       print*,'  1:JANUARY-MARCH'
       print*,'  2:APRIL-JUN'
       print*,'  3:JULY-SEPTEMBER'
       print*,'  4:OCTOBER-DECEMBER'
       read*,cmonth
       print*,'Select Area to be located:1-48'
       print*,'  1:A1   2:A2   3:A3   4:A4   5:A5'
       print*,'    '
       print*,'  6:B1   7:B2   8:B3   9:B4'
       print*,' 10:B5  11:B6  12:B7  13:B8'
       print*,'    '
       print*,'  14:C1  15:C2  16:C3  17:C4  18:C5  19:C6'
       print*,'  20:C7  21:C8  22:C9  23:C10 24:C11'
       print*,'    '
       print*,'  25:D1  26:D2  27:D3  28:D4  29:D5   30:D6'
       print*,'  31:D7  32:D8  33:D9  34:D10 35:D11  36:D12'
       print*,'    '
       print*,'  37:E1  38:E2  39:E3  40:E4  41:E5  42:E6'
       print*,'  43:E7  44:E8  45:E9  46:E10 47:E11 48:E12'
       read*,clocation


       if (cyear.EQ.1)then
       years='1997'
       endif
       if (cyear.EQ.2)then
       years='1998'
       endif
       if (cyear.EQ.3)then
       years='1999'
       endif
       if (cyear.EQ.4)then
       years='2000'
       endif
       if (cyear.EQ.5)then
       years='2001'
       endif
       if (cyear.EQ.6)then
       years='2002'
       endif
       if (cyear.EQ.7)then
       years='2003'
       endif

       if (cmonth.EQ.1)then
       month='q01'
       endif
       if (cmonth.EQ.2)then
       month='q02'
       endif
       if (cmonth.EQ.3)then
       month='q03'
       endif
       if (cmonth.EQ.4)then
```

```
month='q04'
endif

if (cyear.EQ.1)then
if(cmonth.EQ.2)then
nfile=76
bil='1'
elseif (cmonth.EQ.3)then
nfile=125
bil='2'
elseif (cmonth.EQ.4)then
nfile=119
bil='3'
endif
endif
  if(cyear.EQ.2)then
  if (cmonth.EQ.1)then
  nfile=114
  bil='4'
  elseif (cmonth.EQ.2)then
  nfile=87
  bil='5'
  elseif (cmonth.EQ.3)then
  nfile=120
  bil='6'
  elseif (cmonth.EQ.4)then
  nfile=116
  bil='7'
  endif
  endif
if(cyear.EQ.3)then
if(cmonth.EQ.1)then
nfile=104
bil='8'
elseif(cmonth.EQ.2)then
nfile=119
bil='9'
elseif(cmonth.EQ.3)then
nfile=89
bil='10'
elseif(cmonth.EQ.4)then
nfile=119
bil='11'
endif
endif
  if(cyear.EQ.4)then
  if(cmonth.EQ.1)then
  nfile=143
  bil='12'
  elseif(cmonth.EQ.2)then
  nfile=127
  bil='13'
  elseif(cmonth.EQ.3)then
  nfile=121
  bil='14'
  elseif(cmonth.EQ.4)then
  nfile=121
  bil='15'
  endif
  endif
if(cyear.EQ.5)then
if(cmonth.EQ.1)then
nfile=128
bil='16'
elseif(cmonth.EQ.2)then
nfile=144
bil='17'
elseif(cmonth.EQ.3)then
nfile=154
bil='18'
elseif(cmonth.EQ.4)then
nfile=138
bil='19'
endif
endif
  if(cyear.EQ.6)then
```

```
        if(cmonth.EQ.1)then
        nfile=134
        bil='20'
        elseif(cmonth.EQ.2)then
        nfile=134
        bil='21'
        elseif(cmonth.EQ.3)then
        nfile=115
        bil='22'
        elseif(cmonth.EQ.4)then
        nfile=95
        bil='23'
        endif
        endif
       if(cyear.EQ.7)then
       if(cmonth.EQ.1)then
       nfile=138
       bil='24'
       elseif(cmonth.EQ.2)then
       nfile=269
       bil='25'
       elseif(cmonth.EQ.3)then
       nfile=111
       bil='26'
       endif
       endif

C    READING FILENAME
      do 1 num =1,nfile
      write(number,10)num
10    format(I3)
      filenm = number//month//years
      open(unit=5,file=filenm,status='old')


c   Reading the header
      do 100 I=1,52
      if(I.eq.11)then
      read(5,6)ndata
6     format(29x,I5)
      endif
      read(5,*)
100   continue
      do 110 I=1,ndata
      stoper(I)=0
      area(I)=0
      read(5,16)year(I),day(I),hr(I),minute(I),sec(I),y(I),Z(I),sig(I)
     +,SWH(I),U(I)
16    format(I4,1x,I3,1x,I2,1x,I2,1x,f9.6,1x,I9,1x,I9,10x,I4,2x,I2,9x
     +,f8.6)

c Assinging the location name
      if(Y(i).GT.0.AND.Y(i).LE.2000000)then
      if(Z(i).GE.102000000.AND.Z(i).LE.104000000)then
      area(I)= 1
      stoper(I)=1
      elseif(Z(i).GT.104000000.AND.Z(i).LE.106000000)then
      area(I)= 2
      stoper(I)=1
      elseif(Z(i).GT.106000000.AND.Z(i).LE.108000000)then
      area(I)= 3
      stoper(I)=1
      elseif(Z(i).GT.108000000.AND.Z(i).LE.110000000)then
      area(I)= 4
      stoper(I)=1
      elseif(Z(i).GE.118000000.AND.Z(i).LE.120000000)then
      area(I)= 5
      stoper(I)=1
      endif
       elseif(Y(i).GT.2000000.AND.Y(i).LE.4000000)then
       if(Z(i).GE.100000000.AND.Z(i).LE.102000000)then
       area(I)= 6
       stoper(I)=1
       elseif(Z(i).GT.102000000.AND.Z(i).LE.104000000)then
       area(I)= 7
       stoper(I)=1
```

```
 elseif(Z(i).GT.104000000.AND.Z(i).LE.106000000)then
 area(I)= 8
 stoper(I)=1
 elseif(Z(i).GT.106000000.AND.Z(i).LE.108000000)then
 area(I)= 9
 stoper(I)=1
 elseif(Z(i).GT.108000000.AND.Z(i).LE.110000000)then
 area(I)= 10
 stoper(I)=1
 elseif(Z(i).GT.110000000.AND.Z(i).LE.112000000)then
 area(I)= 11
 stoper(I)=1
 elseif(Z(i).GT.112000000.AND.Z(i).LE.114000000)then
 area(I)= 12
 stoper(I)=1
 elseif(Z(i).GE.118000000.AND.Z(i).LE.120000000)then
 area(I)= 13
 stoper(I)=1
 endif
elseif(Y(i).GT.4000000.AND.Y(i).LE.6000000)then
if(Z(i).GE.96000000.AND.Z(i).LE.98000000)then
area(I)= 14
stoper(I)=1
elseif(Z(i).GT.98000000.AND.Z(i).LE.100000000)then
area(I)= 15
stoper(I)=1
elseif(Z(i).GT.100000000.AND.Z(i).LE.102000000)then
area(I)= 16
stoper(I)=1
elseif(Z(i).GT.102000000.AND.Z(i).LE.104000000)then
area(I)= 17
stoper(I)=1
elseif(Z(i).GT.104000000.AND.Z(i).LE.106000000)then
area(I)= 18
stoper(I)=1
elseif(Z(i).GT.106000000.AND.Z(i).LE.108000000)then
area(I)= 19
stoper(I)=1
elseif(Z(i).GT.108000000.AND.Z(i).LE.110000000)then
area(I)= 20
stoper(I)=1
elseif(Z(i).GT.110000000.AND.Z(i).LE.112000000)then
area(I)= 21
stoper(I)=1
elseif(Z(i).GT.112000000.AND.Z(i).LE.114000000)then
area(I)= 22
stoper(I)=1
elseif(Z(i).GT.114000000.AND.Z(i).LE.116000000)then
area(I)= 23
stoper(I)=1
elseif(Z(i).GE.118000000.AND.Z(i).LE.120000000)then
area(I)= 24
stoper(I)=1
endif
 elseif(Y(i).GT.6000000.AND.Y(i).LE.8000000)then
 if(Z(i).GE.96000000.AND.Z(i).LE.98000000)then
 area(I)= 25
 stoper(I)=1
 elseif(Z(i).GT.98000000.AND.Z(i).LE.100000000)then
 area(I)= 26
 stoper(I)=1
 elseif(Z(i).GT.100000000.AND.Z(i).LE.102000000)then
 area(I)= 27
 stoper(I)=1
 elseif(Z(i).GT.102000000.AND.Z(i).LE.104000000)then
 area(I)= 28
 stoper(I)=1
 elseif(Z(i).GT.104000000.AND.Z(i).LE.106000000)then
 area(I)= 29
 stoper(I)=1
 elseif(Z(i).GT.106000000.AND.Z(i).LE.108000000)then
 area(I)= 30
 stoper(I)=1
 elseif(Z(i).GT.108000000.AND.Z(i).LE.110000000)then
 area(I)= 31
 stoper(I)=1
```

```
       elseif(Z(i).GT.110000000.AND.Z(i).LE.112000000)then
       area(I)= 32
       stoper(I)=1
       elseif(Z(i).GT.112000000.AND.Z(i).LE.114000000)then
       area(I)= 33
       stoper(I)=1
       elseif(Z(i).GT.114000000.AND.Z(i).LE.116000000)then
       area(I)= 34
       stoper(I)=1
       elseif(Z(i).GT.116000000.AND.Z(i).LE.118000000)then
       area(I)= 35
       stoper(I)=1
       elseif(Z(i).GT.118000000.AND.Z(i).LE.120000000)then
       area(I)= 36
       stoper(I)=1
       endif
      elseif(Y(i).GT.8000000.AND.Y(i).LE.10000000)then
      if(Z(i).GE.96000000.AND.Z(i).LE.98000000)then
      area(I)= 37
      stoper(I)=1
      elseif(Z(i).GT.98000000.AND.Z(i).LE.100000000)then
      area(I)= 38
      stoper(I)=1
      elseif(Z(i).GT.100000000.AND.Z(i).LE.102000000)then
      area(I)= 39
      stoper(I)=1
      elseif(Z(i).GT.102000000.AND.Z(i).LE.104000000)then
      area(I)= 40
      stoper(I)=1
      elseif(Z(i).GT.104000000.AND.Z(i).LE.106000000)then
      area(I)= 41
      stoper(I)=1
      elseif(Z(i).GT.106000000.AND.Z(i).LE.108000000)then
      area(I)= 42
      stoper(I)=1
      elseif(Z(i).GT.108000000.AND.Z(i).LE.110000000)then
      area(I)= 43
      stoper(I)=1
      elseif(Z(i).GT.110000000.AND.Z(i).LE.112000000)then
      area(I)= 44
      stoper(I)=1
      elseif(Z(i).GT.112000000.AND.Z(i).LE.114000000)then
      area(I)= 45
      stoper(I)=1
      elseif(Z(i).GT.114000000.AND.Z(i).LE.116000000)then
      area(I)= 46
      stoper(I)=1
      elseif(Z(i).GT.116000000.AND.Z(i).LE.118000000)then
      area(I)= 47
      stoper(I)=1
      elseif(Z(i).GT.118000000.AND.Z(i).LE.120000000)then
      area(I)= 48
      stoper(I)=1
      endif
      endif
110   continue

      do 200 I=1,ndata
      if (area(I).EQ.clocation)then
      syear(k)=year(I)
      sday(k)=day(I)
      shr(k)=hr(I)
      sminute(k)=minute(I)
      ssec(k)=sec(I)
      sY(k)=Y(I)
      sZ(k)=Z(I)
      ssig(k)=sig(I)
      sswh(k)=swh(I)
      su(k)=U(I)
      sarea(k)=area(I)
      k=k+1
      endif
      nk=k
200   continue
      close (unit = 5)
1     continue
```

```
C     DISPLAY COLLECTED DATA FROM ALL FILES
c     print*,'  '
c     print*,' Press Any Key for ALL COLLECTED DATA:'
c     read*
c     print*,'  '
     print*,' No.  Year Day Hr  Min   Sec      Y        Z      Sig
    +SWH    U     Area '
      do 400 i = 1,nk-1
      if (sarea(i).eq. 1) then
      name = 'A1'
      loc = '(0N-2N,102E-104E)'
      else if (sarea(i) .eq. 2) then
      name = 'A2'
      loc = '(0N-2N,104E-106E)'
      else if (sarea(i) .eq. 3) then
      name = 'A3'
      loc = '(0N-2N,106E-108E)'
      else if (sarea(i) .eq. 4) then
      name = 'A4'
      loc = '(0N-2N,108E-110E)'
      else if (sarea(i) .eq. 5) then
      name = 'A5'
      loc = '(0N-2N,118E-120E)'
      else if (sarea(i) .eq. 6) then
      name = 'B1'
      loc = '(2N-4N,100E-102E)'
      else if (sarea(i) .eq. 7) then
      name = 'B2'
      loc = '(2N-4N,102E-104E)'
      else if (sarea(i) .eq. 8) then
      name = 'B3'
      loc = '(2N-4N,104E-106E)'
      else if (sarea(i) .eq. 9) then
      name = 'B4'
      loc = '(2N-4N,106E-108E)'
      else if (sarea(i) .eq. 10) then
      name = 'B5'
      loc = '(2N-4N,108E-110E)'
      else if (sarea(i) .eq. 11) then
      name = 'B6'
      loc = '(2N-4N,110E-112E)'
      else if (sarea(i) .eq. 12) then
      name = 'B7'
      loc = '(2N-4N,112E-114E)'
      else if (sarea(i) .eq. 13) then
      name = 'B8'
      loc = '(2N-4N,118E-120E)'
      else if (sarea(i) .eq. 14) then
      name = 'C1'
      loc = '(4N-6N,96E-98E)'
      else if (sarea(i) .eq. 15) then
      name = 'C2'
      loc = '(4N-6N,98E-100E)'
      else if (sarea(i) .eq. 16) then
      name = 'C3'
      loc = '(4N-6N,100E-102E)'
      else if (sarea(i) .eq. 17) then
      name = 'C4'
      loc = '(4N-6N,102E-104E)'
      else if (sarea(i) .eq. 18) then
      name = 'C5'
      loc = '(4N-6N,104E-106E)'
      else if (sarea(i) .eq. 19) then
      name = 'C6'
      loc = '(4N-6N,106E-108E)'
      else if (sarea(i) .eq. 20) then
      name = 'C7'
      loc = '(4N-6N,108E-110E)'
      else if (sarea(i) .eq. 21) then
      name = 'C8'
      loc = '(4N-6N,110E-112E)'
      else if (sarea(i) .eq. 22) then
      name = 'C9'
      loc = '(4N-6N,112E-114E)'
      else if (sarea(i) .eq. 23) then
```

```
name = 'C10'
loc = '(4N-6N,114E-116E)'
else if (sarea(i) .eq. 24) then
name = 'C11'
loc = '(4N-6N,118E-120E)'
else if (sarea(i) .eq. 25) then
name = 'D1'
loc = '(6N-8N,96E-98E)'
else if (sarea(i) .eq. 26) then
name = 'D2'
loc = '(6N-8N,98E-100E)'
else if (sarea(i) .eq. 27) then
name = 'D3'
loc = '(6N-8N,100E-102E)'
else if (sarea(i) .eq. 28) then
name = 'D4'
loc = '(6N-8N,102E-104E)'
else if (sarea(i) .eq. 29) then
name = 'D5'
loc = '(6N-8N,104E-106E)'
else if (sarea(i) .eq. 30) then
name = 'D6'
loc = '(6N-8N,106E-108E)'
else if (sarea(i) .eq. 31) then
name = 'D7'
loc = '(6N-8N,108E-110E)'
else if (sarea(i) .eq. 32) then
name = 'D8'
loc = '(6N-8N,110E-112E)'
else if (sarea(i) .eq. 33) then
name = 'D9'
loc = '(6N-8N,112E-114E)'
else if (sarea(i) .eq. 34) then
name = 'D10'
loc = '(6N-8N,114E-116E)'
else if (sarea(i) .eq. 35) then
name = 'D11'
loc = '(6N-8N,116E-118E)'
else if (sarea(i) .eq. 36) then
name = 'D12'
loc = '(6N-8N,118E-120E)'
else if (sarea(i) .eq. 37) then
name = 'E1'
loc = '(8N-10N,96E-98E)'
else if (sarea(i) .eq. 38) then
name = 'E2'
loc = '(8N-10N,98E-100E)'
else if (sarea(i) .eq. 39) then
name = 'E3'
loc = '(8N-10N,100E-102E)'
else if (sarea(i) .eq. 40) then
name = 'E4'
loc = '(8N-10N,102E-104E)'
else if (sarea(i) .eq. 41) then
name = 'E5'
loc = '(8N-10N,104E-106E)'
else if (sarea(i) .eq. 42) then
name = 'E6'
loc = '(8N-10N,106E-108E)'
else if (sarea(i) .eq. 43) then
name = 'E7'
loc = '(8N-10N,108E-110E)'
else if (sarea(i) .eq. 44) then
name = 'E8'
loc = '(8N-10N,110E-112E)'
else if (sarea(i) .eq. 45) then
name = 'E9'
loc = '(8N-10N,112E-114E)'
else if (sarea(i) .eq. 46) then
name = 'E10'
loc = '(8N-10N,114E-116E)'
else if (sarea(i) .eq. 47) then
name = 'E11'
loc = '(8N-10N,116E-118E)'
else if (sarea(i) .eq. 48) then
name = 'E12'
```

```
          loc = '(8N-10N,118E-120E)'
          end if

      print 19,i,syear(i),sday(i),shr(I),sminute(I),ssec(I),sy(I)
     +,sZ(I),ssig(I),sswh(I),su(I),sarea(I),name
400   continue
19    format(1x,I5,1x,I4,1x,I3,1x,I2,2x,I2,2x,f5.2,1x,I9,1x,I9,1x,I4
     +,2x,I2,3x,f7.4,3x,I2,2x,A3)

c Saving data to output file

c     print*,'Do you want to save the result (y/n) ?'
c     read*, saveras
c     if ((saveras.eq.'y').or.(saveras.eq.'Y'))then
c     print*,'num=',bil
c     print*,'Enter File Name Correctly'
c     read(*,*)savefilenm
      savefilenm='out'//name//years//month
      open(unit=12,file=savefilenm,status='new')
c     read*
      write(12,*)' COLLECTED DATA FOR AREA :',NAME,' ',loc
      write(12,*)'NO OF COLLECTION DATA:',nk-1
      write(12,*)'QUARTER/YEAR:',month,'/',years
      WRITE(12,*)' No.  Year Day  Hr Min  Sec       Y        Z     sig
     + SWH     U       Area          Tz(D)       Tz(G)       Tz(H)'
c     read*
      do 450 i=1,nk-1
      Mo(i)=((sswh(i)*0.1)**2)/4.0
      Ta(i)=(Mo(i)/(86533.36/(2*(ssig(i)*0.01)*62.65)))**0.25
      Wa(i)=2.56*(((sswh(i)*0.1)**2*96.04)/(su(i)/1.026)**4)**0.3
      Tz1(i)=3.6231+(0.0754*Ta(i))+(0.1943*Wa(i))+(-0.0188*(Ta(i))**2)
      sTP(i)=Tz1(i)+(0.1991*Ta(i)*Wa(i))
450   continue

c     read*
      do 451 i=1,nk-1
      T1(i)=((ssig(i)*0.01)*(sswh(i)*0.1)**2)**0.25
      if (T1(i).Lt.0.0001)then
      sTP1(i)= 0
      else
      T2(i)= 0.361+(0.967*LOG10(T1(i)))
      sTP1(I)= 10**(T2(i))
      endif
451   continue

c     read*
      do 452 i=1,nk-1
      if (sswh(i).LE.0)then
      sTP2(i)=0
      else
      B(i)=(0.048*(su(i)**2/(9.8*(sswh(i)*0.1)))**0.67)*9.8
      sTP2(i)=su(i)/B(i)
      endif
452   continue

c     read*
      do 500 i=1,nk-1
      write(12,21)i,syear(i),sday(i),shr(I),sminute(I),ssec(I),sy(I)
     +,sZ(I),ssig(I),sswh(I),su(I),sarea(I),name,sTP(I),sTP1(I),sTP2(I)
21    format(1x,I5,1x,I4,1x,I3,1x,I2,2x,I2,2x,f5.2,1x,I9,1x,I9,1x,I4
     +,2x,I2,3x,f7.4,3x,I2,2x,A3,2x,f10.4,2x,f10.4,2x,f10.4)
500   continue
      close (unit=12)


c     read*
c     print*,'ndata=',nk-1
      count1=0
      count2=0
      count3=0
      count4=0
      count5=0
      count6=0
      count7=0
      count8=0
      count9=0
```

```
count10=0
count11=0
count12=0
count13=0
count14=0
count15=0
count16=0
count17=0
count18=0
count19=0
count20=0
count21=0
count22=0
count23=0
count24=0
count25=0
count26=0
count27=0
count28=0
count29=0
count30=0
count31=0
count32=0
count33=0
count34=0
count35=0
count36=0
count37=0
count38=0
count39=0
count40=0
count41=0
count42=0
count43=0
count44=0
count45=0
count46=0
count47=0
count48=0
count49=0
count50=0
count51=0
count52=0
count53=0
count54=0
count55=0
count56=0
count57=0
count58=0
count59=0
count60=0
count61=0
count62=0
count63=0
count64=0
count65=0
count66=0
count67=0
count68=0
count69=0
count70=0
count71=0
count72=0
count73=0
count74=0
count75=0
count76=0
count77=0
count78=0
count79=0
count80=0
count81=0
count82=0
count83=0
count84=0
count85=0
```

```
count86=0
count87=0
count88=0
count89=0
count90=0
count91=0
count92=0
count93=0
count94=0
count95=0
count96=0
count97=0
count98=0
count99=0
count100=0
count101=0
count102=0
count103=0
count104=0
count105=0
count106=0
count107=0
count108=0
count109=0
count110=0
count111=0
count112=0
count113=0
count114=0
count115=0
count116=0
count117=0
count118=0
count119=0
count120=0
count121=0
count122=0
count123=0
count124=0
count125=0
count126=0
count127=0
count128=0
count129=0
count130=0

do 600 i=1,nk-1
if (sswh(i).GE.00.and.sswh(i).LT.10)then
if (sTP(i).GE.0.and.sTP(i).LT.1)then
count1=count1+1
elseif (sTP(i).GE.1.and.sTP(i).LT.2)then
count2=count2+1
elseif (sTP(i).GE.2.and.sTP(i).LT.3)then
count3=count3+1
elseif (sTP(i).GE.3.and.sTP(i).LT.4)then
count4=count4+1
elseif (sTP(i).GE.4.and.sTP(i).LT.5)then
count5=count5+1
elseif (sTP(i).GE.5.and.sTP(i).LT.6)then
count6=count6+1
elseif (sTP(i).GE.6.and.sTP(i).LT.7)then
count7=count7+1
elseif (sTP(i).GE.7.and.sTP(i).LT.8)then
count8=count8+1
elseif (sTP(i).GE.8.and.sTP(i).LT.9)then
count9=count9+1
elseif (sTP(i).GE.9.and.sTP(i).LT.10)then
count10=count10+1
elseif (sTP(i).GE.10.and.sTP(i).LT.11)then
count11=count11+1
elseif (sTP(i).GE.11.and.sTP(i).LT.12)then
count12=count12+1
elseif (sTP(i).GE.12.and.sTP(i).LT.13)then
count13=count13+1
endif
     elseif (sswh(i).GE.10.and.sswh(i).LT.20)then
```

```
          if (sTP(i).GE.0.and.sTP(i).LT.1)then
          count14=count14+1
          elseif (sTP(i).GE.1.and.sTP(i).LT.2)then
          count15=count15+1
          elseif (sTP(i).GE.2.and.sTP(i).LT.3)then
          count16=count16+1
          elseif (sTP(i).GE.3.and.sTP(i).LT.4)then
          count17=count17+1
          elseif (sTP(i).GE.4.and.sTP(i).LT.5)then
          count18=count18+1
          elseif (sTP(i).GE.5.and.sTP(i).LT.6)then
          count19=count19+1
          elseif (sTP(i).GE.6.and.sTP(i).LT.7)then
          count20=count20+1
          elseif (sTP(i).GE.7.and.sTP(i).LT.8)then
          count21=count21+1
          elseif (sTP(i).GE.8.and.sTP(i).LT.9)then
          count22=count22+1
          elseif (sTP(i).GE.9.and.sTP(i).LT.10)then
          count23=count23+1
          elseif (sTP(i).GE.10.and.sTP(i).LT.11)then
          count24=count24+1
          elseif (sTP(i).GE.11.and.sTP(i).LT.12)then
          count25=count25+1
          elseif (sTP(i).GE.12.and.sTP(i).LT.13)then
          count26=count26+1
          endif
     elseif (sswh(i).GE.20.and.sswh(i).LT.30)then
     if (sTP(i).GE.0.and.sTP(i).LT.1)then
     count27=count27+1
     elseif (sTP(i).GE.1.and.sTP(i).LT.2)then
     count28=count28+1
     elseif (sTP(i).GE.2.and.sTP(i).LT.3)then
     count29=count29+1
     elseif (sTP(i).GE.3.and.sTP(i).LT.4)then
     count30=count30+1
     elseif (sTP(i).GE.4.and.sTP(i).LT.5)then
     count31=count31+1
     elseif (sTP(i).GE.5.and.sTP(i).LT.6)then
     count32=count32+1
     elseif (sTP(i).GE.6.and.sTP(i).LT.7)then
     count33=count33+1
     elseif (sTP(i).GE.7.and.sTP(i).LT.8)then
     count34=count34+1
     elseif (sTP(i).GE.8.and.sTP(i).LT.9)then
     count35=count35+1
     elseif (sTP(i).GE.9.and.sTP(i).LT.10)then
     count36=count36+1
     elseif (sTP(i).GE.10.and.sTP(i).LT.11)then
     count37=count37+1
     elseif (sTP(i).GE.11.and.sTP(i).LT.12)then
     count38=count38+1
     elseif (sTP(i).GE.12.and.sTP(i).LT.13)then
     count39=count39+1
     endif
          elseif (sswh(i).GE.30.and.sswh(i).LT.40)then
          if (sTP(i).GE.0.and.sTP(i).LT.1)then
          count40=count40+1
          elseif (sTP(i).GE.1.and.sTP(i).LT.2)then
          count41=count41+1
          elseif (sTP(i).GE.2.and.sTP(i).LT.3)then
          count42=count42+1
          elseif (sTP(i).GE.3.and.sTP(i).LT.4)then
          count43=count43+1
          elseif (sTP(i).GE.4.and.sTP(i).LT.5)then
          count44=count44+1
          elseif (sTP(i).GE.5.and.sTP(i).LT.6)then
          count45=count45+1
          elseif (sTP(i).GE.6.and.sTP(i).LT.7)then
          count46=count46+1
          elseif (sTP(i).GE.7.and.sTP(i).LT.8)then
          count47=count47+1
          elseif (sTP(i).GE.8.and.sTP(i).LT.9)then
          count48=count48+1
          elseif (sTP(i).GE.9.and.sTP(i).LT.10)then
          count49=count49+1
```

```
     elseif (sTP(i).GE.10.and.sTP(i).LT.11)then
     count50=count50+1
     elseif (sTP(i).GE.11.and.sTP(i).LT.12)then
     count51=count51+1
     elseif (sTP(i).GE.12.and.sTP(i).LT.13)then
     count52=count52+1
     endif
elseif (SSWH(i).GE.40.and.SSWH(i).LT.50)then
if (sTP(i).GE.0.and.sTP(i).LT.1)then
count53=count53+1
elseif (sTP(i).GE.1.and.sTP(i).LT.2)then
count54=count54+1
elseif (sTP(i).GE.2.and.sTP(i).LT.3)then
count55=count55+1
elseif (sTP(i).GE.3.and.sTP(i).LT.4)then
count56=count56+1
elseif (sTP(i).GE.4.and.sTP(i).LT.5)then
count57=count57+1
elseif (sTP(i).GE.5.and.sTP(i).LT.6)then
count58=count58+1
elseif (sTP(i).GE.6.and.sTP(i).LT.7)then
count59=count59+1
elseif (sTP(i).GE.7.and.sTP(i).LT.8)then
count60=count60+1
elseif (sTP(i).GE.8.and.sTP(i).LT.9)then
count61=count61+1
elseif (sTP(i).GE.9.and.sTP(i).LT.10)then
count62=count62+1
elseif (sTP(i).GE.10.and.sTP(i).LT.11)then
count63=count63+1
elseif (sTP(i).GE.11.and.sTP(i).LT.12)then
count64=count64+1
elseif (sTP(i).GE.12.and.sTP(i).LT.13)then
count65=count65+1
endif
     elseif (SSWH(i).GE.50.and.SSWH(i).LT.60)then
     if (sTP(i).GE.0.and.sTP(i).LT.1)then
     count66=count66+1
     elseif (sTP(i).GE.1.and.sTP(i).LT.2)then
     count67=count67+1
     elseif (sTP(i).GE.2.and.sTP(i).LT.3)then
     count68=count68+1
     elseif (sTP(i).GE.3.and.sTP(i).LT.4)then
     count69=count69+1
     elseif (sTP(i).GE.4.and.sTP(i).LT.5)then
     count70=count70+1
     elseif (sTP(i).GE.5.and.sTP(i).LT.6)then
     count71=count71+1
     elseif (sTP(i).GE.6.and.sTP(i).LT.7)then
     count72=count72+1
     elseif (sTP(i).GE.7.and.sTP(i).LT.8)then
     count73=count73+1
     elseif (sTP(i).GE.8.and.sTP(i).LT.9)then
     count74=count74+1
     elseif (sTP(i).GE.9.and.sTP(i).LT.10)then
     count75=count75+1
     elseif (sTP(i).GE.10.and.sTP(i).LT.11)then
     count76=count76+1
     elseif (sTP(i).GE.11.and.sTP(i).LT.12)then
     count77=count77+1
     elseif (sTP(i).GE.12.and.sTP(i).LT.13)then
     count78=count78+1
     endif
 elseif (SSWH(i).GE.60.and.SSWH(i).LT.70)then
 if (sTP(i).GE.0.and.sTP(i).LT.1)then
 count79=count79+1
 elseif (sTP(i).GE.1.and.sTP(i).LT.2)then
 count80=count80+1
 elseif (sTP(i).GE.2.and.sTP(i).LT.3)then
 count81=count81+1
 elseif (sTP(i).GE.3.and.sTP(i).LT.4)then
 count82=count82+1
 elseif (sTP(i).GE.4.and.sTP(i).LT.5)then
 count83=count83+1
 elseif (sTP(i).GE.5.and.sTP(i).LT.6)then
 count84=count84+1
```

```
elseif (sTP(i).GE.6.and.sTP(i).LT.7)then
count85=count85+1
elseif (sTP(i).GE.7.and.sTP(i).LT.8)then
count86=count86+1
elseif (sTP(i).GE.8.and.sTP(i).LT.9)then
count87=count87+1
elseif (sTP(i).GE.9.and.sTP(i).LT.10)then
count88=count88+1
elseif (sTP(i).GE.10.and.sTP(i).LT.11)then
count89=count89+1
elseif (sTP(i).GE.11.and.sTP(i).LT.12)then
count90=count90+1
elseif (sTP(i).GE.12.and.sTP(i).LT.13)then
count91=count91+1
endif
    elseif (SSWH(i).GE.70.and.SSWH(i).LT.80)then
    if (sTP(i).GE.0.and.sTP(i).LT.1)then
    count92=count92+1
    elseif (sTP(i).GE.1.and.sTP(i).LT.2)then
    count93=count93+1
    elseif (sTP(i).GE.2.and.sTP(i).LT.3)then
    count94=count94+1
    elseif (sTP(i).GE.3.and.sTP(i).LT.4)then
    count95=count95+1
    elseif (sTP(i).GE.4.and.sTP(i).LT.5)then
    count96=count96+1
    elseif (sTP(i).GE.5.and.sTP(i).LT.6)then
    count97=count97+1
    elseif (sTP(i).GE.6.and.sTP(i).LT.7)then
    count98=count98+1
    elseif (sTP(i).GE.7.and.sTP(i).LT.8)then
    count99=count99+1
    elseif (sTP(i).GE.8.and.sTP(i).LT.9)then
    count100=count100+1
    elseif (sTP(i).GE.9.and.sTP(i).LT.10)then
    count101=count101+1
    elseif (sTP(i).GE.10.and.sTP(i).LT.11)then
    count102=count102+1
    elseif (sTP(i).GE.11.and.sTP(i).LT.12)then
    count103=count103+1
    elseif (sTP(i).GE.12.and.sTP(i).LT.13)then
    count104=count104+1
    endif
elseif (SSWH(i).GE.80.and.SSWH(i).LT.90)then
if (sTP(i).GE.0.and.sTP(i).LT.1)then
count105=count105+1
elseif (sTP(i).GE.1.and.sTP(i).LT.2)then
count106=count106+1
elseif (sTP(i).GE.2.and.sTP(i).LT.3)then
count107=count107+1
elseif (sTP(i).GE.3.and.sTP(i).LT.4)then
count108=count108+1
elseif (sTP(i).GE.4.and.sTP(i).LT.5)then
count109=count109+1
elseif (sTP(i).GE.5.and.sTP(i).LT.6)then
count110=count110+1
elseif (sTP(i).GE.6.and.sTP(i).LT.7)then
count111=count111+1
elseif (sTP(i).GE.7.and.sTP(i).LT.8)then
count112=count112+1
elseif (sTP(i).GE.8.and.sTP(i).LT.9)then
count113=count113+1
elseif (sTP(i).GE.9.and.sTP(i).LT.10)then
count114=count114+1
elseif (sTP(i).GE.10.and.sTP(i).LT.11)then
count115=count115+1
elseif (sTP(i).GE.11.and.sTP(i).LT.12)then
count116=count116+1
elseif (sTP(i).GE.12.and.sTP(i).LT.13)then
count117=count117+1
endif
    elseif (SSWH(i).GE.90.and.SSWH(i).LE.100)then
    if (sTP(i).GE.0.and.sTP(i).LT.1)then
    count118=count118+1
    elseif (sTP(i).GE.1.and.sTP(i).LT.2)then
    count119=count119+1
```

```
            elseif (sTP(i).GE.2.and.sTP(i).LT.3)then
            count120=count120+1
            elseif (sTP(i).GE.3.and.sTP(i).LT.4)then
            count121=count121+1
            elseif (sTP(i).GE.4.and.sTP(i).LT.5)then
            count122=count122+1
            elseif (sTP(i).GE.5.and.sTP(i).LT.6)then
            count123=count123+1
            elseif (sTP(i).GE.6.and.sTP(i).LT.7)then
            count124=count124+1
            elseif (sTP(i).GE.7.and.sTP(i).LT.8)then
            count125=count125+1
            elseif (sTP(i).GE.8.and.sTP(i).LT.9)then
            count126=count126+1
            elseif (sTP(i).GE.9.and.sTP(i).LT.10)then
            count127=count127+1
            elseif (sTP(i).GE.10.and.sTP(i).LT.11)then
            count128=count128+1
            elseif (sTP(i).GE.11.and.sTP(i).LT.12)then
            count129=count129+1
            elseif (sTP(i).GE.12.and.sTP(i).LT.13)then
            count130=count130+1
            endif
            endif
600   continue

c      read*
      qi1=count1
      qi2=count2
      qi3=count3
      qi4=count4
      qi5=count5
      qi6=count6
      qi7=count7
      qi8=count8
      qi9=count9
      qi10=count10
      qi11=count11
      qi12=count12
      qi13=count13
      qi14=count14
      qi15=count15
      qi16=count16
      qi17=count17
      qi18=count18
      qi19=count19
      qi20=count20
      qi21=count21
      qi22=count22
      qi23=count23
      qi24=count24
      qi25=count25
      qi26=count26
      qi27=count27
      qi28=count28
      qi29=count29
      qi30=count30
      qi31=count31
      qi32=count32
      qi33=count33
      qi34=count34
      qi35=count35
      qi36=count36
      qi37=count37
      qi38=count38
      qi39=count39
      qi40=count40
      qi41=count41
      qi42=count42
      qi43=count43
      qi44=count44
      qi45=count45
      qi46=count46
      qi47=count47
      qi48=count48
      qi49=count49
```

```
qi50=count50
qi51=count51
qi52=count52
qi53=count53
qi54=count54
qi55=count55
qi56=count56
qi57=count57
qi58=count58
qi59=count59
qi60=count60
qi61=count61
qi62=count62
qi63=count63
qi64=count64
qi65=count65
qi66=count66
qi67=count67
qi68=count68
qi69=count69
qi70=count70
qi71=count71
qi72=count72
qi73=count73
qi74=count74
qi75=count75
qi76=count76
qi77=count77
qi78=count78
qi79=count79
qi80=count80
qi81=count81
qi82=count82
qi83=count83
qi84=count84
qi85=count85
qi86=count86
qi87=count87
qi88=count88
qi89=count89
qi90=count90
qi91=count91
qi92=count92
qi93=count93
qi94=count94
qi95=count95
qi96=count96
qi97=count97
qi98=count98
qi99=count99
qi100=count100
qi101=count101
qi102=count102
qi103=count103
qi104=count104
qi105=count105
qi106=count106
qi107=count107
qi108=count108
qi109=count109
qi110=count110
qi111=count111
qi112=count112
qi113=count113
qi114=count114
qi115=count115
qi116=count116
qi117=count117
qi118=count118
qi119=count119
qi120=count120
qi121=count121
qi122=count122
qi123=count123
qi124=count124
qi125=count125
```

```
qi126=count126
qi127=count127
qi128=count128
qi129=count129
qi130=count130
d=nk-1
pi1=(qi1/d)
pi2=(qi2/d)
pi3=(qi3/d)
pi4=(qi4/d)
pi5=(qi5/d)
pi6=(qi6/d)
pi7=(qi7/d)
pi8=(qi8/d)
pi9=(qi9/d)
pi10=(qi10/d)
pi11=(qi11/d)
pi12=(qi12/d)
pi13=(qi13/d)
pi14=(qi14/d)
pi15 =(qi15/d)
pi16 =(qi16/d)
pi17 =(qi17/d)
pi18 =(qi18/d)
pi19 =(qi19/d)
pi20 =(qi20/d)
pi21 =(qi21/d)
pi22 =(qi22/d)
pi23 =(qi23/d)
pi24 =(qi24/d)
pi25 =(qi25/d)
pi26 =(qi26/d)
pi27 =(qi27/d)
pi28 =(qi28/d)
pi29 =(qi29/d)
pi30 =(qi30/d)
pi31 =(qi31/d)
pi32 =(qi32/d)
pi33 =(qi33/d)
pi34 =(qi34/d)
pi35 =(qi35/d)
pi36 =(qi36/d)
pi37 =(qi37/d)
pi38 =(qi38/d)
pi39 =(qi39/d)
pi40 =(qi40/d)
pi41 =(qi41/d)
pi42 =(qi42/d)
pi43 =(qi43/d)
pi44 =(qi44/d)
pi45 =(qi45/d)
pi46 =(qi46/d)
pi47 =(qi47/d)
pi48 =(qi48/d)
pi49 =(qi49/d)
pi50 =(qi50/d)
pi51 =(qi51/d)
pi52 =(qi52/d)
pi53 =(qi53/d)
pi54 =(qi54/d)
pi55 =(qi55/d)
pi56 =(qi56/d)
pi57 =(qi57/d)
pi58 =(qi58/d)
pi59 =(qi59/d)
pi60 =(qi60/d)
pi61 =(qi61/d)
pi62 =(qi62/d)
pi63 =(qi63/d)
pi64 =(qi64/d)
pi65 =(qi65/d)
pi66 =(qi66/d)
pi67 =(qi67/d)
pi68 =(qi68/d)
pi69 =(qi69/d)
pi70 =(qi70/d)
```

```
      pi71=(qi71/d)
      pi72=(qi72/d)
      pi73=(qi73/d)
      pi74=(qi74/d)
      pi75=(qi75/d)
      pi76=(qi76/d)
      pi77=(qi77/d)
      pi78=(qi78/d)
      pi79=(qi79/d)
      pi80=(qi80/d)
      pi81=(qi81/d)
      pi82=(qi82/d)
      pi83=(qi83/d)
      pi84=(qi84/d)
      pi85=(qi85/d)
      pi86=(qi86/d)
      pi87=(qi87/d)
      pi88=(qi88/d)
      pi89=(qi89/d)
      pi90=(qi90/d)
      pi91=(qi91/d)
      pi92=(qi92/d)
      pi93=(qi93/d)
      pi94=(qi94/d)
      pi95=(qi95/d)
      pi96=(qi96/d)
      pi97=(qi97/d)
      pi98=(qi98/d)
      pi99=(qi99/d)
      pi100=(qi100/d)
      pi101=(qi101/d)
      pi102=(qi102/d)
      pi103=(qi103/d)
      pi104=(qi104/d)
      pi105=(qi105/d)
      pi106=(qi106/d)
      pi107=(qi107/d)
      pi108=(qi108/d)
      pi109=(qi109/d)
      pi110=(qi110/d)
      pi111=(qi111/d)
      pi112=(qi112/d)
      pi113=(qi113/d)
      pi114=(qi114/d)
      pi115 =(qi115/d)
      pi116 =(qi116/d)
      pi117 =(qi117/d)
      pi118 =(qi118/d)
      pi119 =(qi119/d)
      pi120 =(qi120/d)
      pi121 =(qi121/d)
      pi122 =(qi122/d)
      pi123 =(qi123/d)
      pi124 =(qi124/d)
      pi125 =(qi125/d)
      pi126 =(qi126/d)
      pi127 =(qi127/d)
      pi128 =(qi128/d)
      pi129 =(qi129/d)
      pi130 =(qi130/d)
c      print*,'Enter File Name for Prodis Davies File'
c      read(*,*)saveprodis
      saveprodis='dav'//name//years//month
      open(unit=18,file=saveprodis,status='new')
      write(18,*)'PROBABILITY DISTRIBUTION FOR AREA:',NAME,' ',loc
      write(18,*)'QUARTER/YEAR:',month,'/',years
      write(18,*)'METHOD: DAVIES et al.'
      write(18,*)'      '
      write(18,*)'SWH/Tz     0-1            1-2            2-3
     +     3-4            4-5            5-6            6-7'
      write(18,*)'0-1m',pi1,pi2,pi3,pi4,pi5,pi6,pi7
      write(18,*)'1-2m',pi14,pi15,pi16,pi17,pi18,pi19,pi20
      write(18,*)'2-3m',pi27,pi28,pi29,pi30,pi31,pi32,pi33
      write(18,*)'3-4m',pi40,pi41,pi42,pi43,pi44,pi45,pi46
      write(18,*)'4-5m',pi53,pi54,pi55,pi56,pi57,pi58,pi59
      write(18,*)'5-6m',pi66,pi67,pi68,pi69,pi70,pi71,pi72
```

```
      write(18,*)'6-7m',pi79,pi80,pi81,pi82,pi83,pi84,pi85
      write(18,*)'7-8m',pi92,pi93,pi94,pi95,pi96,pi97,pi98
      write(18,*)'8-9m',pi105,pi106,pi107,pi108,pi109,pi110,pi111
      write(18,*)'9-10m',pi118,pi119,pi120,pi121,pi122,pi123,pi124
      write(18,*)'     '
      write(18,*)'     '
      write(18,*)'     '
      write(18,*)'SWH/Tz      7-8            8-9            9-10
     +      10-11            11-12            12-13'
      write(18,*)'0-1m',pi8,pi9,pi10,pi11,pi12,pi13
      write(18,*)'1-2m',pi21,pi22,pi23,pi24,pi25,pi26
      write(18,*)'2-3m',pi34,pi35,pi36,pi37,pi38,pi39
      write(18,*)'3-4m',pi47,pi48,pi49,pi50,pi51,pi52
      write(18,*)'4-5m',pi60,pi61,pi62,pi63,pi64,pi65
      write(18,*)'5-6m',pi73,pi74,pi75,pi76,pi77,pi78
      write(18,*)'6-7m',pi86,pi87,pi88,pi89,pi90,pi91
      write(18,*)'7-8m',pi99,pi100,pi101,pi102,pi103,pi104
      write(18,*)'8-9m',pi112,pi113,pi114,pi115,pi116,pi117
      write(18,*)'9-10m',pi125,pi126,pi127,pi128,pi129,pi130
      close (unit=18)

c       read*
      coun1=0
      coun2=0
      coun3=0
      coun4=0
      coun5=0
      coun6=0
      coun7=0
      coun8=0
      coun9=0
      coun10=0
      coun11=0
      coun12=0
      coun13=0
      coun14=0
      coun15=0
      coun16=0
      coun17=0
      coun18=0
      coun19=0
      coun20=0
      coun21=0
      coun22=0
      coun23=0
      coun24=0
      coun25=0
      coun26=0
      coun27=0
      coun28=0
      coun29=0
      coun30=0
      coun31=0
      coun32=0
      coun33=0
      coun34=0
      coun35=0
      coun36=0
      coun37=0
      coun38=0
      coun39=0
      coun40=0
      coun41=0
      coun42=0
      coun43=0
      coun44=0
      coun45=0
      coun46=0
      coun47=0
      coun48=0
      coun49=0
      coun50=0
      coun51=0
      coun52=0
      coun53=0
      coun54=0
```

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coun55=0
coun56=0
coun57=0
coun58=0
coun59=0
coun60=0
coun61=0
coun62=0
coun63=0
coun64=0
coun65=0
coun66=0
coun67=0
coun68=0
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coun73=0
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coun103=0
coun104=0
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coun107=0
coun108=0
coun109=0
coun110=0
coun111=0
coun112=0
coun113=0
coun114=0
coun115=0
coun116=0
coun117=0
coun118=0
coun119=0
coun120=0
coun121=0
coun122=0
coun123=0
coun124=0
coun125=0
coun126=0
coun127=0
coun128=0
coun129=0
coun130=0
```

```
do 601 i=1,nk-1
if (sswh(i).GE.00.and.sswh(i).LT.10)then
if (sTP1(i).GE.0.and.sTP1(i).LT.1)then
coun1=coun1+1
elseif (sTP1(i).GE.1.and.sTP1(i).LT.2)then
coun2=coun2+1
elseif (sTP1(i).GE.2.and.sTP1(i).LT.3)then
coun3=coun3+1
elseif (sTP1(i).GE.3.and.sTP1(i).LT.4)then
coun4=coun4+1
elseif (sTP1(i).GE.4.and.sTP1(i).LT.5)then
coun5=coun5+1
elseif (sTP1(i).GE.5.and.sTP1(i).LT.6)then
coun6=coun6+1
elseif (sTP1(i).GE.6.and.sTP1(i).LT.7)then
coun7=coun7+1
elseif (sTP1(i).GE.7.and.sTP1(i).LT.8)then
coun8=coun8+1
elseif (sTP1(i).GE.8.and.sTP1(i).LT.9)then
coun9=coun9+1
elseif (sTP1(i).GE.9.and.sTP1(i).LT.10)then
coun10=coun10+1
elseif (sTP1(i).GE.10.and.sTP1(i).LT.11)then
coun11=coun11+1
elseif (sTP1(i).GE.11.and.sTP1(i).LT.12)then
coun12=coun12+1
elseif (sTP1(i).GE.12.and.sTP1(i).LT.13)then
coun13=coun13+1
endif
        elseif (sswh(i).GE.10.and.sswh(i).LT.20)then
        if (sTP1(i).GE.0.and.sTP1(i).LT.1)then
        coun14=coun14+1
        elseif (sTP1(i).GE.1.and.sTP1(i).LT.2)then
        coun15=coun15+1
        elseif (sTP1(i).GE.2.and.sTP1(i).LT.3)then
        coun16=coun16+1
        elseif (sTP1(i).GE.3.and.sTP1(i).LT.4)then
        coun17=coun17+1
        elseif (sTP1(i).GE.4.and.sTP1(i).LT.5)then
        coun18=coun18+1
        elseif (sTP1(i).GE.5.and.sTP1(i).LT.6)then
        coun19=coun19+1
        elseif (sTP1(i).GE.6.and.sTP1(i).LT.7)then
        coun20=coun20+1
        elseif (sTP1(i).GE.7.and.sTP1(i).LT.8)then
        coun21=coun21+1
        elseif (sTP1(i).GE.8.and.sTP1(i).LT.9)then
        coun22=coun22+1
        elseif (sTP1(i).GE.9.and.sTP1(i).LT.10)then
        coun23=coun23+1
        elseif (sTP1(i).GE.10.and.sTP1(i).LT.11)then
        coun24=coun24+1
        elseif (sTP1(i).GE.11.and.sTP1(i).LT.12)then
        coun25=coun25+1
        elseif (sTP1(i).GE.12.and.sTP1(i).LT.13)then
        coun26=coun26+1
        endif
elseif (sswh(i).GE.20.and.sswh(i).LT.30)then
if (sTP1(i).GE.0.and.sTP1(i).LT.1)then
coun27=coun27+1
elseif (sTP1(i).GE.1.and.sTP1(i).LT.2)then
coun28=coun28+1
elseif (sTP1(i).GE.2.and.sTP1(i).LT.3)then
coun29=coun29+1
elseif (sTP1(i).GE.3.and.sTP1(i).LT.4)then
coun30=coun30+1
elseif (sTP1(i).GE.4.and.sTP1(i).LT.5)then
coun31=coun31+1
elseif (sTP1(i).GE.5.and.sTP1(i).LT.6)then
coun32=coun32+1
elseif (sTP1(i).GE.6.and.sTP1(i).LT.7)then
coun33=coun33+1
elseif (sTP1(i).GE.7.and.sTP1(i).LT.8)then
coun34=coun34+1
elseif (sTP1(i).GE.8.and.sTP1(i).LT.9)then
```

```
coun35=coun35+1
elseif (sTP1(i).GE.9.and.sTP1(i).LT.10)then
coun36=coun36+1
elseif (sTP1(i).GE.10.and.sTP1(i).LT.11)then
coun37=coun37+1
elseif (sTP1(i).GE.11.and.sTP1(i).LT.12)then
coun38=coun38+1
elseif (sTP1(i).GE.12.and.sTP1(i).LT.13)then
coun39=coun39+1
endif
      elseif (sswh(i).GE.30.and.sswh(i).LT.40)then
      if (sTP1(i).GE.0.and.sTP1(i).LT.1)then
      coun40=coun40+1
      elseif (sTP1(i).GE.1.and.sTP1(i).LT.2)then
      coun41=coun41+1
      elseif (sTP1(i).GE.2.and.sTP1(i).LT.3)then
      coun42=coun42+1
      elseif (sTP1(i).GE.3.and.sTP1(i).LT.4)then
      coun43=coun43+1
      elseif (sTP1(i).GE.4.and.sTP1(i).LT.5)then
      coun44=coun44+1
      elseif (sTP1(i).GE.5.and.sTP1(i).LT.6)then
      coun45=coun45+1
      elseif (sTP1(i).GE.6.and.sTP1(i).LT.7)then
      coun46=coun46+1
      elseif (sTP1(i).GE.7.and.sTP1(i).LT.8)then
      coun47=coun47+1
      elseif (sTP1(i).GE.8.and.sTP1(i).LT.9)then
      coun48=coun48+1
      elseif (sTP1(i).GE.9.and.sTP1(i).LT.10)then
      coun49=coun49+1
      elseif (sTP1(i).GE.10.and.sTP1(i).LT.11)then
      coun50=coun50+1
      elseif (sTP1(i).GE.11.and.sTP1(i).LT.12)then
      coun51=coun51+1
      elseif (sTP1(i).GE.12.and.sTP1(i).LT.13)then
      coun52=coun52+1
      endif
elseif (SSWH(i).GE.40.and.SSWH(i).LT.50)then
if (sTP1(i).GE.0.and.sTP1(i).LT.1)then
coun53=coun53+1
elseif (sTP1(i).GE.1.and.sTP1(i).LT.2)then
coun54=coun54+1
elseif (sTP1(i).GE.2.and.sTP1(i).LT.3)then
coun55=coun55+1
elseif (sTP1(i).GE.3.and.sTP1(i).LT.4)then
coun56=coun56+1
elseif (sTP1(i).GE.4.and.sTP1(i).LT.5)then
coun57=coun57+1
elseif (sTP1(i).GE.5.and.sTP1(i).LT.6)then
coun58=coun58+1
elseif (sTP1(i).GE.6.and.sTP1(i).LT.7)then
coun59=coun59+1
elseif (sTP1(i).GE.7.and.sTP1(i).LT.8)then
coun60=coun60+1
elseif (sTP1(i).GE.8.and.sTP1(i).LT.9)then
coun61=coun61+1
elseif (sTP1(i).GE.9.and.sTP1(i).LT.10)then
coun62=coun62+1
elseif (sTP1(i).GE.10.and.sTP1(i).LT.11)then
coun63=coun63+1
elseif (sTP1(i).GE.11.and.sTP1(i).LT.12)then
coun64=coun64+1
elseif (sTP1(i).GE.12.and.sTP1(i).LT.13)then
coun65=coun65+1
endif
      elseif (SSWH(i).GE.50.and.SSWH(i).LT.60)then
      if (sTP1(i).GE.0.and.sTP1(i).LT.1)then
      coun66=coun66+1
      elseif (sTP1(i).GE.1.and.sTP1(i).LT.2)then
      coun67=coun67+1
      elseif (sTP1(i).GE.2.and.sTP1(i).LT.3)then
      coun68=coun68+1
      elseif (sTP1(i).GE.3.and.sTP1(i).LT.4)then
      coun69=coun69+1
      elseif (sTP1(i).GE.4.and.sTP1(i).LT.5)then
```

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    coun70=coun70+1
    elseif (sTP1(i).GE.5.and.sTP1(i).LT.6)then
    coun71=coun71+1
    elseif (sTP1(i).GE.6.and.sTP1(i).LT.7)then
    coun72=coun72+1
    elseif (sTP1(i).GE.7.and.sTP1(i).LT.8)then
    coun73=coun73+1
    elseif (sTP1(i).GE.8.and.sTP1(i).LT.9)then
    coun74=coun74+1
    elseif (sTP1(i).GE.9.and.sTP1(i).LT.10)then
    coun75=coun75+1
    elseif (sTP1(i).GE.10.and.sTP1(i).LT.11)then
    coun76=coun76+1
    elseif (sTP1(i).GE.11.and.sTP1(i).LT.12)then
    coun77=coun77+1
    elseif (sTP1(i).GE.12.and.sTP1(i).LT.13)then
    coun78=coun78+1
    endif
elseif (SSWH(i).GE.60.and.SSWH(i).LT.70)then
if (sTP1(i).GE.0.and.sTP1(i).LT.1)then
coun79=coun79+1
elseif (sTP1(i).GE.1.and.sTP1(i).LT.2)then
coun80=coun80+1
elseif (sTP1(i).GE.2.and.sTP1(i).LT.3)then
coun81=coun81+1
elseif (sTP1(i).GE.3.and.sTP1(i).LT.4)then
coun82=coun82+1
elseif (sTP1(i).GE.4.and.sTP1(i).LT.5)then
coun83=coun83+1
elseif (sTP1(i).GE.5.and.sTP1(i).LT.6)then
coun84=coun84+1
elseif (sTP1(i).GE.6.and.sTP1(i).LT.7)then
coun85=coun85+1
elseif (sTP1(i).GE.7.and.sTP1(i).LT.8)then
coun86=coun86+1
elseif (sTP1(i).GE.8.and.sTP1(i).LT.9)then
coun87=coun87+1
elseif (sTP1(i).GE.9.and.sTP1(i).LT.10)then
coun88=coun88+1
elseif (sTP1(i).GE.10.and.sTP1(i).LT.11)then
coun89=coun89+1
elseif (sTP1(i).GE.11.and.sTP1(i).LT.12)then
coun90=coun90+1
elseif (sTP1(i).GE.12.and.sTP1(i).LT.13)then
coun91=coun91+1
endif
    elseif (SSWH(i).GE.70.and.SSWH(i).LT.80)then
    if (sTP1(i).GE.0.and.sTP1(i).LT.1)then
    coun92=coun92+1
    elseif (sTP1(i).GE.1.and.sTP1(i).LT.2)then
    coun93=coun93+1
    elseif (sTP1(i).GE.2.and.sTP1(i).LT.3)then
    coun94=coun94+1
    elseif (sTP1(i).GE.3.and.sTP1(i).LT.4)then
    coun95=coun95+1
    elseif (sTP1(i).GE.4.and.sTP1(i).LT.5)then
    coun96=coun96+1
    elseif (sTP1(i).GE.5.and.sTP1(i).LT.6)then
    coun97=coun97+1
    elseif (sTP1(i).GE.6.and.sTP1(i).LT.7)then
    coun98=coun98+1
    elseif (sTP1(i).GE.7.and.sTP1(i).LT.8)then
    coun99=coun99+1
    elseif (sTP1(i).GE.8.and.sTP1(i).LT.9)then
    coun100=coun100+1
    elseif (sTP1(i).GE.9.and.sTP1(i).LT.10)then
    coun101=coun101+1
    elseif (sTP1(i).GE.10.and.sTP1(i).LT.11)then
    coun102=coun102+1
    elseif (sTP1(i).GE.11.and.sTP1(i).LT.12)then
    coun103=coun103+1
    elseif (sTP1(i).GE.12.and.sTP1(i).LT.13)then
    coun104=coun104+1
    endif
elseif (SSWH(i).GE.80.and.SSWH(i).LT.90)then
if (sTP1(i).GE.0.and.sTP1(i).LT.1)then
```

```
      coun105=coun105+1
      elseif (sTP1(i).GE.1.and.sTP1(i).LT.2)then
      coun106=coun106+1
      elseif (sTP1(i).GE.2.and.sTP1(i).LT.3)then
      coun107=coun107+1
      elseif (sTP1(i).GE.3.and.sTP1(i).LT.4)then
      coun108=coun108+1
      elseif (sTP1(i).GE.4.and.sTP1(i).LT.5)then
      coun109=coun109+1
      elseif (sTP1(i).GE.5.and.sTP1(i).LT.6)then
      coun110=coun110+1
      elseif (sTP1(i).GE.6.and.sTP1(i).LT.7)then
      coun111=coun111+1
      elseif (sTP1(i).GE.7.and.sTP1(i).LT.8)then
      coun112=coun112+1
      elseif (sTP1(i).GE.8.and.sTP1(i).LT.9)then
      coun113=coun113+1
      elseif (sTP1(i).GE.9.and.sTP1(i).LT.10)then
      coun114=coun114+1
      elseif (sTP1(i).GE.10.and.sTP1(i).LT.11)then
      coun115=coun115+1
      elseif (sTP1(i).GE.11.and.sTP1(i).LT.12)then
      coun116=coun116+1
      elseif (sTP1(i).GE.12.and.sTP1(i).LT.13)then
      coun117=coun117+1
      endif
         elseif (SSWH(i).GE.90.and.SSWH(i).LE.100)then
         if (sTP1(i).GE.0.and.sTP1(i).LT.1)then
         coun118=coun118+1
         elseif (sTP1(i).GE.1.and.sTP1(i).LT.2)then
         coun119=coun119+1
         elseif (sTP1(i).GE.2.and.sTP1(i).LT.3)then
         coun120=coun120+1
         elseif (sTP1(i).GE.3.and.sTP1(i).LT.4)then
         coun121=coun121+1
         elseif (sTP1(i).GE.4.and.sTP1(i).LT.5)then
         coun122=coun122+1
         elseif (sTP1(i).GE.5.and.sTP1(i).LT.6)then
         coun123=coun123+1
         elseif (sTP1(i).GE.6.and.sTP1(i).LT.7)then
         coun124=coun124+1
         elseif (sTP1(i).GE.7.and.sTP1(i).LT.8)then
         coun125=coun125+1
         elseif (sTP1(i).GE.8.and.sTP1(i).LT.9)then
         coun126=coun126+1
         elseif (sTP1(i).GE.9.and.sTP1(i).LT.10)then
         coun127=coun127+1
         elseif (sTP1(i).GE.10.and.sTP1(i).LT.11)then
         coun128=coun128+1
         elseif (sTP1(i).GE.11.and.sTP1(i).LT.12)then
         coun129=coun129+1
         elseif (sTP1(i).GE.12.and.sTP1(i).LT.13)then
         coun130=coun130+1
         endif
         endif
601   continue

c     read*
     q1=coun1
     q2=coun2
     q3=coun3
     q4=coun4
     q5=coun5
     q6=coun6
     q7=coun7
     q8=coun8
     q9=coun9
     q10=coun10
     q11=coun11
     q12=coun12
     q13=coun13
     q14=coun14
     q15=coun15
     q16=coun16
     q17=coun17
     q18=coun18
```

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q19=coun19
q20=coun20
q21=coun21
q22=coun22
q23=coun23
q24=coun24
q25=coun25
q26=coun26
q27=coun27
q28=coun28
q29=coun29
q30=coun30
q31=coun31
q32=coun32
q33=coun33
q34=coun34
q35=coun35
q36=coun36
q37=coun37
q38=coun38
q39=coun39
q40=coun40
q41=coun41
q42=coun42
q43=coun43
q44=coun44
q45=coun45
q46=coun46
q47=coun47
q48=coun48
q49=coun49
q50=coun50
q51=coun51
q52=coun52
q53=coun53
q54=coun54
q55=coun55
q56=coun56
q57=coun57
q58=coun58
q59=coun59
q60=coun60
q61=coun61
q62=coun62
q63=coun63
q64=coun64
q65=coun65
q66=coun66
q67=coun67
q68=coun68
q69=coun69
q70=coun70
q71=coun71
q72=coun72
q73=coun73
q74=coun74
q75=coun75
q76=coun76
q77=coun77
q78=coun78
q79=coun79
q80=coun80
q81=coun81
q82=coun82
q83=coun83
q84=coun84
q85=coun85
q86=coun86
q87=coun87
q88=coun88
q89=coun89
q90=coun90
q91=coun91
q92=coun92
q93=coun93
q94=coun94
```

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q95=coun95
q96=coun96
q97=coun97
q98=coun98
q99=coun99
q100=coun100
q101=coun101
q102=coun102
q103=coun103
q104=coun104
q105=coun105
q106=coun106
q107=coun107
q108=coun108
q109=coun109
q110=coun110
q111=coun111
q112=coun112
q113=coun113
q114=coun114
q115=coun115
q116=coun116
q117=coun117
q118=coun118
q119=coun119
q120=coun120
q121=coun121
q122=coun122
q123=coun123
q124=coun124
q125=coun125
q126=coun126
q127=coun127
q128=coun128
q129=coun129
q130=coun130
d=nk-1
p1=(q1/d)
p2=(q2/d)
p3=(q3/d)
p4=(q4/d)
p5=(q5/d)
p6=(q6/d)
p7=(q7/d)
p8=(q8/d)
p9=(q9/d)
p10=(q10/d)
p11=(q11/d)
p12=(q12/d)
p13=(q13/d)
p14=(q14/d)
p15 =(q15/d)
p16 =(q16/d)
p17 =(q17/d)
p18 =(q18/d)
p19 =(q19/d)
p20 =(q20/d)
p21 =(q21/d)
p22 =(q22/d)
p23 =(q23/d)
p24 =(q24/d)
p25 =(q25/d)
p26 =(q26/d)
p27 =(q27/d)
p28 =(q28/d)
p29 =(q29/d)
p30 =(q30/d)
p31 =(q31/d)
p32 =(q32/d)
p33 =(q33/d)
p34 =(q34/d)
p35 =(q35/d)
p36 =(q36/d)
p37 =(q37/d)
p38 =(q38/d)
p39 =(q39/d)
```

```
p40 =(q40/d)
p41 =(q41/d)
p42 =(q42/d)
p43 =(q43/d)
p44 =(q44/d)
p45 =(q45/d)
p46 =(q46/d)
p47 =(q47/d)
p48 =(q48/d)
p49 =(q49/d)
p50 =(q50/d)
p51 =(q51/d)
p52 =(q52/d)
p53 =(q53/d)
p54 =(q54/d)
p55 =(q55/d)
p56 =(q56/d)
p57 =(q57/d)
p58 =(q58/d)
p59 =(q59/d)
p60 =(q60/d)
p61 =(q61/d)
p62 =(q62/d)
p63 =(q63/d)
p64 =(q64/d)
p65 =(q65/d)
p66 =(q66/d)
p67 =(q67/d)
p68 =(q68/d)
p69 =(q69/d)
p70 =(q70/d)
p71=(q71/d)
p72=(q72/d)
p73=(q73/d)
p74=(q74/d)
p75=(q75/d)
p76=(q76/d)
p77=(q77/d)
p78=(q78/d)
p79=(q79/d)
p80=(q80/d)
p81=(q81/d)
p82=(q82/d)
p83=(q83/d)
p84=(q84/d)
p85=(q85/d)
p86=(q86/d)
p87=(q87/d)
p88=(q88/d)
p89=(q89/d)
p90=(q90/d)
p91=(q91/d)
p92=(q92/d)
p93=(q93/d)
p94=(q94/d)
p95=(q95/d)
p96=(q96/d)
p97=(q97/d)
p98=(q98/d)
p99=(q99/d)
p100=(q100/d)
p101=(q101/d)
p102=(q102/d)
p103=(q103/d)
p104=(q104/d)
p105=(q105/d)
p106=(q106/d)
p107=(q107/d)
p108=(q108/d)
p109=(q109/d)
p110=(q110/d)
p111=(q111/d)
p112=(q112/d)
p113=(q113/d)
p114=(q114/d)
p115 =(q115/d)
```

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      p116 =(q116/d)
      p117 =(q117/d)
      p118 =(q118/d)
      p119 =(q119/d)
      p120 =(q120/d)
      p121 =(q121/d)
      p122 =(q122/d)
      p123 =(q123/d)
      p124 =(q124/d)
      p125 =(q125/d)
      p126 =(q126/d)
      p127 =(q127/d)
      p128 =(q128/d)
      p129 =(q129/d)
      p130 =(q130/d)
c      print*,'Enter File Name for Prodis Gommen File'
c      read(*,*)saveprodisi
      saveprodisi='gom'//name//years//month
      open(unit=19,file=saveprodisi,status='new')
      write(19,*)'PROBABILITY DISTRIBUTION FOR AREA:',NAME,' ',loc
      write(19,*)'QUARTER/YEAR:',month,'/',years
      write(19,*)'METHOD:GOMMENGINGER et al. METHOD'
      write(19,*)'     '
      write(19,*)'SWH/Tz     0-1          1-2          2-3
     +     3-4          4-5          5-6          6-7'
      write(19,*)'0-1m',p1,p2,p3,p4,p5,p6,p7
      write(19,*)'1-2m',p14,p15,p16,p17,p18,p19,p20
      write(19,*)'2-3m',p27,p28,p29,p30,p31,p32,p33
      write(19,*)'3-4m',p40,p41,p42,p43,p44,p45,p46
      write(19,*)'4-5m',p53,p54,p55,p56,p57,p58,p59
      write(19,*)'5-6m',p66,p67,p68,p69,p70,p71,p72
      write(19,*)'6-7m',p79,p80,p81,p82,p83,p84,p85
      write(19,*)'7-8m',p92,p93,p94,p95,p96,p97,p98
      write(19,*)'8-9m',p105,p106,p107,p108,p109,p110,p111
      write(19,*)'9-10m',p118,p119,p120,p121,p122,p123,p124
      write(19,*)'     '
      write(19,*)'     '
      write(19,*)'     '
      write(19,*)'SWH/Tz      7-8          8-9          9-10
     +      10-11          11-12          12-13'
      write(19,*)'0-1m',p8,p9,p10,p11,p12,p13
      write(19,*)'1-2m',p21,p22,p23,p24,p25,p26
      write(19,*)'2-3m',p34,p35,p36,p37,p38,p39
      write(19,*)'3-4m',p47,p48,p49,p50,p51,p52
      write(19,*)'4-5m',p60,p61,p62,p63,p64,p65
      write(19,*)'5-6m',p73,p74,p75,p76,p77,p78
      write(19,*)'6-7m',p86,p87,p88,p89,p90,p91
      write(19,*)'7-8m',p99,p100,p101,p102,p103,p104
      write(19,*)'8-9m',p112,p113,p114,p115,p116,p117
      write(19,*)'9-10m',p125,p126,p127,p128,p129,p130
      close (unit=19)

c      read*
      counn1=0
      counn2=0
      counn3=0
      counn4=0
      counn5=0
      counn6=0
      counn7=0
      counn8=0
      counn9=0
      counn10=0
      counn11=0
      counn12=0
      counn13=0
      counn14=0
      counn15=0
      counn16=0
      counn17=0
      counn18=0
      counn19=0
      counn20=0
      counn21=0
      counn22=0
      counn23=0
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counn24=0
counn25=0
counn26=0
counn27=0
counn28=0
counn29=0
counn30=0
counn31=0
counn32=0
counn33=0
counn34=0
counn35=0
counn36=0
counn37=0
counn38=0
counn39=0
counn40=0
counn41=0
counn42=0
counn43=0
counn44=0
counn45=0
counn46=0
counn47=0
counn48=0
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counn50=0
counn51=0
counn52=0
counn53=0
counn54=0
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counn57=0
counn58=0
counn59=0
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counn63=0
counn64=0
counn65=0
counn66=0
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counn79=0
counn80=0
counn81=0
counn82=0
counn83=0
counn84=0
counn85=0
counn86=0
counn87=0
counn88=0
counn89=0
counn90=0
counn91=0
counn92=0
counn93=0
counn94=0
counn95=0
counn96=0
counn97=0
counn98=0
counn99=0
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counn100=0
counn101=0
counn102=0
counn103=0
counn104=0
counn105=0
counn106=0
counn107=0
counn108=0
counn109=0
counn110=0
counn111=0
counn112=0
counn113=0
counn114=0
counn115=0
counn116=0
counn117=0
counn118=0
counn119=0
counn120=0
counn121=0
counn122=0
counn123=0
counn124=0
counn125=0
counn126=0
counn127=0
counn128=0
counn129=0
counn130=0

do 602 i=1,nk-1
if (sswh(i).GE.00.and.sswh(i).LT.10)then
if (sTP2(i).GE.0.and.sTP2(i).LT.1)then
counn1=counn1+1
elseif (sTP2(i).GE.1.and.sTP2(i).LT.2)then
counn2=counn2+1
elseif (sTP2(i).GE.2.and.sTP2(i).LT.3)then
counn3=counn3+1
elseif (sTP2(i).GE.3.and.sTP2(i).LT.4)then
counn4=counn4+1
elseif (sTP2(i).GE.4.and.sTP2(i).LT.5)then
counn5=counn5+1
elseif (sTP2(i).GE.5.and.sTP2(i).LT.6)then
counn6=counn6+1
elseif (sTP2(i).GE.6.and.sTP2(i).LT.7)then
counn7=counn7+1
elseif (sTP2(i).GE.7.and.sTP2(i).LT.8)then
counn8=counn8+1
elseif (sTP2(i).GE.8.and.sTP2(i).LT.9)then
counn9=counn9+1
elseif (sTP2(i).GE.9.and.sTP2(i).LT.10)then
counn10=counn10+1
elseif (sTP2(i).GE.10.and.sTP2(i).LT.11)then
counn11=counn11+1
elseif (sTP2(i).GE.11.and.sTP2(i).LT.12)then
counn12=counn12+1
elseif (sTP2(i).GE.12.and.sTP2(i).LT.13)then
counn13=counn13+1
endif
        elseif (sswh(i).GE.10.and.sswh(i).LT.20)then
        if (sTP2(i).GE.0.and.sTP2(i).LT.1)then
        counn14=counn14+1
        elseif (sTP2(i).GE.1.and.sTP2(i).LT.2)then
        counn15=counn15+1
        elseif (sTP2(i).GE.2.and.sTP2(i).LT.3)then
        counn16=counn16+1
        elseif (sTP2(i).GE.3.and.sTP2(i).LT.4)then
        counn17=counn17+1
        elseif (sTP2(i).GE.4.and.sTP2(i).LT.5)then
        counn18=counn18+1
        elseif (sTP2(i).GE.5.and.sTP2(i).LT.6)then
        counn19=counn19+1
        elseif (sTP2(i).GE.6.and.sTP2(i).LT.7)then
        counn20=counn20+1
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          elseif (sTP2(i).GE.7.and.sTP2(i).LT.8)then
          counn21=counn21+1
          elseif (sTP2(i).GE.8.and.sTP2(i).LT.9)then
          counn22=counn22+1
          elseif (sTP2(i).GE.9.and.sTP2(i).LT.10)then
          counn23=counn23+1
          elseif (sTP2(i).GE.10.and.sTP2(i).LT.11)then
          counn24=counn24+1
          elseif (sTP2(i).GE.11.and.sTP2(i).LT.12)then
          counn25=counn25+1
          elseif (sTP2(i).GE.12.and.sTP2(i).LT.13)then
          counn26=counn26+1
          endif
elseif (sswh(i).GE.20.and.sswh(i).LT.30)then
if (sTP2(i).GE.0.and.sTP2(i).LT.1)then
counn27=counn27+1
elseif (sTP2(i).GE.1.and.sTP2(i).LT.2)then
counn28=counn28+1
elseif (sTP2(i).GE.2.and.sTP2(i).LT.3)then
counn29=counn29+1
elseif (sTP2(i).GE.3.and.sTP2(i).LT.4)then
counn30=counn30+1
elseif (sTP2(i).GE.4.and.sTP2(i).LT.5)then
counn31=counn31+1
elseif (sTP2(i).GE.5.and.sTP2(i).LT.6)then
counn32=counn32+1
elseif (sTP2(i).GE.6.and.sTP2(i).LT.7)then
counn33=counn33+1
elseif (sTP2(i).GE.7.and.sTP2(i).LT.8)then
counn34=counn34+1
elseif (sTP2(i).GE.8.and.sTP2(i).LT.9)then
counn35=counn35+1
elseif (sTP2(i).GE.9.and.sTP2(i).LT.10)then
counn36=counn36+1
elseif (sTP2(i).GE.10.and.sTP2(i).LT.11)then
counn37=counn37+1
elseif (sTP2(i).GE.11.and.sTP2(i).LT.12)then
counn38=counn38+1
elseif (sTP2(i).GE.12.and.sTP2(i).LT.13)then
counn39=counn39+1
endif
          elseif (sswh(i).GE.30.and.sswh(i).LT.40)then
          if (sTP2(i).GE.0.and.sTP2(i).LT.1)then
          counn40=counn40+1
          elseif (sTP2(i).GE.1.and.sTP2(i).LT.2)then
          counn41=counn41+1
          elseif (sTP2(i).GE.2.and.sTP2(i).LT.3)then
          counn42=counn42+1
          elseif (sTP2(i).GE.3.and.sTP2(i).LT.4)then
          counn43=counn43+1
          elseif (sTP2(i).GE.4.and.sTP2(i).LT.5)then
          counn44=counn44+1
          elseif (sTP2(i).GE.5.and.sTP2(i).LT.6)then
          counn45=counn45+1
          elseif (sTP2(i).GE.6.and.sTP2(i).LT.7)then
          counn46=counn46+1
          elseif (sTP2(i).GE.7.and.sTP2(i).LT.8)then
          counn47=counn47+1
          elseif (sTP2(i).GE.8.and.sTP2(i).LT.9)then
          counn48=counn48+1
          elseif (sTP2(i).GE.9.and.sTP2(i).LT.10)then
          counn49=counn49+1
          elseif (sTP2(i).GE.10.and.sTP2(i).LT.11)then
          counn50=counn50+1
          elseif (sTP2(i).GE.11.and.sTP2(i).LT.12)then
          counn51=counn51+1
          elseif (sTP2(i).GE.12.and.sTP2(i).LT.13)then
          counn52=counn52+1
          endif
elseif (SSWH(i).GE.40.and.SSWH(i).LT.50)then
if (sTP2(i).GE.0.and.sTP2(i).LT.1)then
counn53=counn53+1
elseif (sTP2(i).GE.1.and.sTP2(i).LT.2)then
counn54=counn54+1
elseif (sTP2(i).GE.2.and.sTP2(i).LT.3)then
counn55=counn55+1
```

```
elseif (sTP2(i).GE.3.and.sTP2(i).LT.4)then
counn56=counn56+1
elseif (sTP2(i).GE.4.and.sTP2(i).LT.5)then
counn57=counn57+1
elseif (sTP2(i).GE.5.and.sTP2(i).LT.6)then
counn58=counn58+1
elseif (sTP2(i).GE.6.and.sTP2(i).LT.7)then
counn59=counn59+1
elseif (sTP2(i).GE.7.and.sTP2(i).LT.8)then
counn60=counn60+1
elseif (sTP2(i).GE.8.and.sTP2(i).LT.9)then
counn61=counn61+1
elseif (sTP2(i).GE.9.and.sTP2(i).LT.10)then
counn62=counn62+1
elseif (sTP2(i).GE.10.and.sTP2(i).LT.11)then
counn63=counn63+1
elseif (sTP2(i).GE.11.and.sTP2(i).LT.12)then
counn64=counn64+1
elseif (sTP2(i).GE.12.and.sTP2(i).LT.13)then
counn65=counn65+1
endif
     elseif (SSWH(i).GE.50.and.SSWH(i).LT.60)then
     if (sTP2(i).GE.0.and.sTP2(i).LT.1)then
     counn66=counn66+1
     elseif (sTP2(i).GE.1.and.sTP2(i).LT.2)then
     counn67=counn67+1
     elseif (sTP2(i).GE.2.and.sTP2(i).LT.3)then
     counn68=counn68+1
     elseif (sTP2(i).GE.3.and.sTP2(i).LT.4)then
     counn69=counn69+1
     elseif (sTP2(i).GE.4.and.sTP2(i).LT.5)then
     counn70=counn70+1
     elseif (sTP2(i).GE.5.and.sTP2(i).LT.6)then
     counn71=counn71+1
     elseif (sTP2(i).GE.6.and.sTP2(i).LT.7)then
     counn72=counn72+1
     elseif (sTP2(i).GE.7.and.sTP2(i).LT.8)then
     counn73=counn73+1
     elseif (sTP2(i).GE.8.and.sTP2(i).LT.9)then
     counn74=counn74+1
     elseif (sTP2(i).GE.9.and.sTP2(i).LT.10)then
     counn75=counn75+1
     elseif (sTP2(i).GE.10.and.sTP2(i).LT.11)then
     counn76=counn76+1
     elseif (sTP2(i).GE.11.and.sTP2(i).LT.12)then
     counn77=counn77+1
     elseif (sTP2(i).GE.12.and.sTP2(i).LT.13)then
     counn78=counn78+1
     endif
 elseif (SSWH(i).GE.60.and.SSWH(i).LT.70)then
 if (sTP2(i).GE.0.and.sTP2(i).LT.1)then
 counn79=counn79+1
 elseif (sTP2(i).GE.1.and.sTP2(i).LT.2)then
 counn80=counn80+1
 elseif (sTP2(i).GE.2.and.sTP2(i).LT.3)then
 counn81=counn81+1
 elseif (sTP2(i).GE.3.and.sTP2(i).LT.4)then
 counn82=counn82+1
 elseif (sTP2(i).GE.4.and.sTP2(i).LT.5)then
 counn83=counn83+1
 elseif (sTP2(i).GE.5.and.sTP2(i).LT.6)then
 counn84=counn84+1
 elseif (sTP2(i).GE.6.and.sTP2(i).LT.7)then
 counn85=counn85+1
 elseif (sTP2(i).GE.7.and.sTP2(i).LT.8)then
 counn86=counn86+1
 elseif (sTP2(i).GE.8.and.sTP2(i).LT.9)then
 counn87=counn87+1
 elseif (sTP2(i).GE.9.and.sTP2(i).LT.10)then
 counn88=counn88+1
 elseif (sTP2(i).GE.10.and.sTP2(i).LT.11)then
 counn89=counn89+1
 elseif (sTP2(i).GE.11.and.sTP2(i).LT.12)then
 coun90=counn90+1
 elseif (sTP2(i).GE.12.and.sTP2(i).LT.13)then
 counn91=counn91+1
```

```
endif
       elseif (SSWH(i).GE.70.and.SSWH(i).LT.80)then
       if (sTP2(i).GE.0.and.sTP2(i).LT.1)then
       counn92=counn92+1
       elseif (sTP2(i).GE.1.and.sTP2(i).LT.2)then
       counn93=counn93+1
       elseif (sTP2(i).GE.2.and.sTP2(i).LT.3)then
       counn94=counn94+1
       elseif (sTP2(i).GE.3.and.sTP2(i).LT.4)then
       counn95=counn95+1
       elseif (sTP2(i).GE.4.and.sTP2(i).LT.5)then
       counn96=counn96+1
       elseif (sTP2(i).GE.5.and.sTP2(i).LT.6)then
       counn97=counn97+1
       elseif (sTP2(i).GE.6.and.sTP2(i).LT.7)then
       counn98=counn98+1
       elseif (sTP2(i).GE.7.and.sTP2(i).LT.8)then
       counn99=counn99+1
       elseif (sTP2(i).GE.8.and.sTP2(i).LT.9)then
       counn100=counn100+1
       elseif (sTP2(i).GE.9.and.sTP2(i).LT.10)then
       counn101=counn101+1
       elseif (sTP2(i).GE.10.and.sTP2(i).LT.11)then
       counn102=counn102+1
       elseif (sTP2(i).GE.11.and.sTP2(i).LT.12)then
       counn103=counn103+1
       elseif (sTP2(i).GE.12.and.sTP2(i).LT.13)then
       counn104=counn104+1
       endif
elseif (SSWH(i).GE.80.and.SSWH(i).LT.90)then
if (sTP2(i).GE.0.and.sTP2(i).LT.1)then
counn105=counn105+1
elseif (sTP2(i).GE.1.and.sTP2(i).LT.2)then
counn106=counn106+1
elseif (sTP2(i).GE.2.and.sTP2(i).LT.3)then
counn107=counn107+1
elseif (sTP2(i).GE.3.and.sTP2(i).LT.4)then
counn108=counn108+1
elseif (sTP2(i).GE.4.and.sTP2(i).LT.5)then
counn109=counn109+1
elseif (sTP2(i).GE.5.and.sTP2(i).LT.6)then
counn110=counn110+1
elseif (sTP2(i).GE.6.and.sTP2(i).LT.7)then
counn111=counn111+1
elseif (sTP2(i).GE.7.and.sTP2(i).LT.8)then
counn112=counn112+1
elseif (sTP2(i).GE.8.and.sTP2(i).LT.9)then
counn113=counn113+1
elseif (sTP2(i).GE.9.and.sTP2(i).LT.10)then
counn114=counn114+1
elseif (sTP2(i).GE.10.and.sTP2(i).LT.11)then
counn115=counn115+1
elseif (sTP2(i).GE.11.and.sTP2(i).LT.12)then
counn116=counn116+1
elseif (sTP2(i).GE.12.and.sTP2(i).LT.13)then
counn117=counn117+1
endif
       elseif (SSWH(i).GE.90.and.SSWH(i).LE.100)then
       if (sTP2(i).GE.0.and.sTP2(i).LT.1)then
       counn118=counn118+1
       elseif (sTP2(i).GE.1.and.sTP2(i).LT.2)then
       counn119=counn119+1
       elseif (sTP2(i).GE.2.and.sTP2(i).LT.3)then
       counn120=counn120+1
       elseif (sTP2(i).GE.3.and.sTP2(i).LT.4)then
       counn121=counn121+1
       elseif (sTP2(i).GE.4.and.sTP2(i).LT.5)then
       counn122=counn122+1
       elseif (sTP2(i).GE.5.and.sTP2(i).LT.6)then
       counn123=counn123+1
       elseif (sTP2(i).GE.6.and.sTP2(i).LT.7)then
       counn124=counn124+1
       elseif (sTP2(i).GE.7.and.sTP2(i).LT.8)then
       counn125=counn125+1
       elseif (sTP2(i).GE.8.and.sTP2(i).LT.9)then
       counn126=counn126+1
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```
            elseif (sTP2(i).GE.9.and.sTP2(i).LT.10)then
            counn127=counn127+1
            elseif (sTP2(i).GE.10.and.sTP2(i).LT.11)then
            counn128=counn128+1
            elseif (sTP2(i).GE.11.and.sTP2(i).LT.12)then
            counn129=counn129+1
            elseif (sTP2(i).GE.12.and.sTP2(i).LT.13)then
            counn130=counn130+1
            endif
            endif
602   continue

c      read*
      qu1=counn1
      qu2=counn2
      qu3=counn3
      qu4=counn4
      qu5=counn5
      qu6=counn6
      qu7=counn7
      qu8=counn8
      qu9=counn9
      qu10=counn10
      qu11=counn11
      qu12=counn12
      qu13=counn13
      qu14=counn14
      qu15=counn15
      qu16=counn16
      qu17=counn17
      qu18=counn18
      qu19=counn19
      qu20=counn20
      qu21=counn21
      qu22=counn22
      qu23=counn23
      qu24=counn24
      qu25=counn25
      qu26=counn26
      qu27=counn27
      qu28=counn28
      qu29=counn29
      qu30=counn30
      qu31=counn31
      qu32=counn32
      qu33=counn33
      qu34=counn34
      qu35=counn35
      qu36=counn36
      qu37=counn37
      qu38=counn38
      qu39=counn39
      qu40=counn40
      qu41=counn41
      qu42=counn42
      qu43=counn43
      qu44=counn44
      qu45=counn45
      qu46=counn46
      qu47=counn47
      qu48=counn48
      qu49=counn49
      qu50=counn50
      qu51=counn51
      qu52=counn52
      qu53=counn53
      qu54=counn54
      qu55=counn55
      qu56=counn56
      qu57=counn57
      qu58=counn58
      qu59=counn59
      qu60=counn60
      qu61=counn61
      qu62=counn62
      qu63=counn63
```

```
qu64=counn64
qu65=counn65
qu66=counn66
qu67=counn67
qu68=counn68
qu69=counn69
qu70=counn70
qu71=counn71
qu72=counn72
qu73=counn73
qu74=counn74
qu75=counn75
qu76=counn76
qu77=counn77
qu78=counn78
qu79=counn79
qu80=counn80
qu81=counn81
qu82=counn82
qu83=counn83
qu84=counn84
qu85=counn85
qu86=counn86
qu87=counn87
qu88=counn88
qu89=counn89
qu90=counn90
qu91=counn91
qu92=counn92
qu93=counn93
qu94=counn94
qu95=counn95
qu96=counn96
qu97=counn97
qu98=counn98
qu99=counn99
qu100=counn100
qu101=counn101
qu102=counn102
qu103=counn103
qu104=counn104
qu105=counn105
qu106=counn106
qu107=counn107
qu108=counn108
qu109=counn109
qu110=counn110
qu111=counn111
qu112=counn112
qu113=counn113
qu114=counn114
qu115=counn115
qu116=counn116
qu117=counn117
qu118=counn118
qu119=counn119
qu120=counn120
qu121=counn121
qu122=counn122
qu123=counn123
qu124=counn124
qu125=counn125
qu126=counn126
qu127=counn127
qu128=counn128
qu129=counn129
qu130=counn130
d=nk-1
pu1=(qu1/d)
pu2=(qu2/d)
pu3=(qu3/d)
pu4=(qu4/d)
pu5=(qu5/d)
pu6=(qu6/d)
pu7=(qu7/d)
pu8=(qu8/d)
```

```
pu9=(qu9/d)
pu10=(qu10/d)
pu11=(qu11/d)
pu12=(qu12/d)
pu13=(qu13/d)
pu14=(qu14/d)
pu15 =(qu15/d)
pu16 =(qu16/d)
pu17 =(qu17/d)
pu18 =(qu18/d)
pu19 =(qu19/d)
pu20 =(qu20/d)
pu21 =(qu21/d)
pu22 =(qu22/d)
pu23 =(qu23/d)
pu24 =(qu24/d)
pu25 =(qu25/d)
pu26 =(qu26/d)
pu27 =(qu27/d)
pu28 =(qu28/d)
pu29 =(qu29/d)
pu30 =(qu30/d)
pu31 =(qu31/d)
pu32 =(qu32/d)
pu33 =(qu33/d)
pu34 =(qu34/d)
pu35 =(qu35/d)
pu36 =(qu36/d)
pu37 =(qu37/d)
pu38 =(qu38/d)
pu39 =(qu39/d)
pu40 =(qu40/d)
pu41 =(qu41/d)
pu42 =(qu42/d)
pu43 =(qu43/d)
pu44 =(qu44/d)
pu45 =(qu45/d)
pu46 =(qu46/d)
pu47 =(qu47/d)
pu48 =(qu48/d)
pu49 =(qu49/d)
pu50 =(qu50/d)
pu51 =(qu51/d)
pu52 =(qu52/d)
pu53 =(qu53/d)
pu54 =(qu54/d)
pu55 =(qu55/d)
pu56 =(qu56/d)
pu57 =(qu57/d)
pu58 =(qu58/d)
pu59 =(qu59/d)
pu60 =(qu60/d)
pu61 =(qu61/d)
pu62 =(qu62/d)
pu63 =(qu63/d)
pu64 =(qu64/d)
pu65 =(qu65/d)
pu66 =(qu66/d)
pu67 =(qu67/d)
pu68 =(qu68/d)
pu69 =(qu69/d)
pu70 =(qu70/d)
pu71=(qu71/d)
pu72=(qu72/d)
pu73=(qu73/d)
pu74=(qu74/d)
pu75=(qu75/d)
pu76=(qu76/d)
pu77=(qu77/d)
pu78=(qu78/d)
pu79=(qu79/d)
pu80=(qu80/d)
pu81=(qu81/d)
pu82=(qu82/d)
pu83=(qu83/d)
pu84=(qu84/d)
```

```
      pu85=(qu85/d)
      pu86=(qu86/d)
      pu87=(qu87/d)
      pu88=(qu88/d)
      pu89=(qu89/d)
      pu90=(qu90/d)
      pu91=(qu91/d)
      pu92=(qu92/d)
      pu93=(qu93/d)
      pu94=(qu94/d)
      pu95=(qu95/d)
      pu96=(qu96/d)
      pu97=(qu97/d)
      pu98=(qu98/d)
      pu99=(qu99/d)
      pu100=(qu100/d)
      pu101=(qu101/d)
      pu102=(qu102/d)
      pu103=(qu103/d)
      pu104=(qu104/d)
      pu105=(qu105/d)
      pu106=(qu106/d)
      pu107=(qu107/d)
      pu108=(qu108/d)
      pu109=(qu109/d)
      pu110=(qu110/d)
      pu111=(qu111/d)
      pu112=(qu112/d)
      pu113=(qu113/d)
      pu114=(qu114/d)
      pu115 =(qu115/d)
      pu116 =(qu116/d)
      pu117 =(qu117/d)
      pu118 =(qu118/d)
      pu119 =(qu119/d)
      pu120 =(qu120/d)
      pu121 =(qu121/d)
      pu122 =(qu122/d)
      pu123 =(qu123/d)
      pu124 =(qu124/d)
      pu125 =(qu125/d)
      pu126 =(qu126/d)
      pu127 =(qu127/d)
      pu128 =(qu128/d)
      pu129 =(qu129/d)
      pu130 =(qu130/d)
c      print*,'Enter File Name for Prodis Hwang File'
c      read(*,*)saveprodissi
      saveprodissi='hwa'//name//years//month
      open(unit=20,file=saveprodissi,status='new')
      write(20,*)'PROBABILITY DISTRIBUTION FOR AREA:',NAME,' ',loc
      write(20,*)'QUARTER/YEAR:',month,'/',years
      write(20,*)'METHOD:HWANG et al. METHOD'
      write(20,*)'     '
      write(20,*)'SWH/Tz     0-1           1-2            2-3
     +      3-4             4-5             5-6             6-7'
      write(20,*)'0-1m',pu1,pu2,pu3,pu4,pu5,pu6,pu7
      write(20,*)'1-2m',pu14,pu15,pu16,pu17,pu18,pu19,pu20
      write(20,*)'2-3m',pu27,pu28,pu29,pu30,pu31,pu32,pu33
      write(20,*)'3-4m',pu40,pu41,pu42,pu43,pu44,pu45,pu46
      write(20,*)'4-5m',pu53,pu54,pu55,pu56,pu57,pu58,pu59
      write(20,*)'5-6m',pu66,pu67,pu68,pu69,pu70,pu71,pu72
      write(20,*)'6-7m',pu79,pu80,pu81,pu82,pu83,pu84,pu85
      write(20,*)'7-8m',pu92,pu93,pu94,pu95,pu96,pu97,pu98
      write(20,*)'8-9m',pu105,pu106,pu107,pu108,pu109,pu110,pu111
      write(20,*)'9-10m',pu118,pu119,pu120,pu121,pu122,pu123,pu124
      write(20,*)'     '
      write(20,*)'     '
      write(20,*)'     '
      write(20,*)'SWH/Tz      7-8           8-9           9-10
     +      10-11           11-12           12-13'
      write(20,*)'0-1m',pu8,pu9,pu10,pu11,pu12,pu13
      write(20,*)'1-2m',pu21,pu22,pu23,pu24,pu25,pu26
      write(20,*)'2-3m',pu34,pu35,pu36,pu37,pu38,pu39
      write(20,*)'3-4m',pu47,pu48,pu49,pu50,pu51,pu52
      write(20,*)'4-5m',pu60,pu61,pu62,pu63,pu64,pu65
```

```
      write(20,*)'5-6m',pu73,pu74,pu75,pu76,pu77,pu78
      write(20,*)'6-7m',pu86,pu87,pu88,pu89,pu90,pu91
      write(20,*)'7-8m',pu99,pu100,pu101,pu102,pu103,pu104
      write(20,*)'8-9m',pu112,pu113,pu114,pu115,pu116,pu117
      write(20,*)'9-10m',pu125,pu126,pu127,pu128,pu129,pu130
      close (unit=20)
c      endif
c Changing to other area
c      print*,'Change to new location? (y/n)'
c      read*,newlocation
c      if (newlocation.eq.'Y'.or.newlocation.eq.'y')then
c      go to 1000
c      endif
       END
```

Appendix D: Program code to automate the procedures