ABSTRACT

Among a variety of elements, the nearshore wave climate is considered to be the most important aspect to explain erosion problems along the coast. Due to the fact that available data is limited, numerical models are valuable and necessary tools to apply. This study is initiated with the main objective to study the nearshore wave climate of the project area at Nam Dinh coast in Viet Nam by a 2D wave SWAN model in order to investigate the erosion problem along the coast.

SWAN (acronym for ***S****imulating of* ***Wa****ves* ***N****earshore*) is a third generation wave model, which has been widely applied to simulate wave conditions in many complex field cases in the Netherlands. However, it has never been used in Viet Nam. Thus the achievement of the study may be considered as documentation for future researches of this model in Viet Nam cases.

Within this research, at first a SWAN model was set-up based on available data. This includes a sensitivity analysis and model calibration. Then a series of computations were carried out for the application of the model for a mean statistical year. Subsequently, the computed results from the SWAN model were used to identify sediment transport rates. These were compared to actual values in order to investigate whether the 2D wave model can predict the erosion adequately.

One of the main results of this study was that the observed sediment transport was qualitatively in accordance with the sediment transport result of the 2D wave model. This emphasized the importance 2D effects to obtain realistic results.

In this study, several drawbacks of SWAN have been identified. They include the inconvenient procedure of pre- and post processing in applying SWAN and the convergence problem when activating all physical processes in the model simulations.

The study also showed the importance of sufficient wind data in the computational grid. The assumption of uniform wind field in computational grid may lead to inaccurate results in particular with respect to the mean wave direction.

For an improvement of the results, the study recommended amongst others that future research should try to generate a variable wind field in the computational grid.

ACKNOWLEDGEMENT

This thesis work was done according to the requirement of the Master of Science degree of the International Institute for Infrastructural, Hydraulic and Environmental Engineering (IHE), Delft, the Netherlands.

First of all, I would like to express my sincere gratitude to my supervisors, Ir. Henk Jan Verhagen and Ir. Mick van der Wegen for their guidance, valuable suggestions, and insightful comments on my work.

Special thanks also to my Mentor, Dr. Randa M. Hassan, for her kind assistance and support in so many ways.

I wish to extend my feelings of gratitude to all members of IHE, especially the Department of Hydraulic Engineering, Prof. Dr. Bela Petry and Ir. Roland De Heer for their assistance during my study.

I am grateful to CICAT project for providing financial support. Especially the efforts of the Rector Prof. Dr. Le Kim Truyen, Dr. Vu Minh Cat and Mr Jan Van Der Laan HWRU/CICAT project for giving me the opportunity to study at IHE.

I am greatly indebted to my employer, the Section of Construction Material, Ha Noi Water Resource University for creating good conditions during my study.

In particular, I owe a special word of thanks to:

> *Dr. Nguyen Manh Hung from Institute of Mechanics for his enthusiasm and support in providing data and technical assistance; Prof. Holthijsen from TU Delft for his great help in technical assistance; Prof. Dr. Arthur E.Mynett from WL/Delft Hydraulic for his unconditional support in initiating the data collecting process; Dr. Lambe from WL/Delft Hydraulic for providing excellent digital map; Nghiem Tien Lam from HWRU for his great technical assistance; Bas Wijdeven from TU Delft for sharing some of the useful data and information related to the study; Nguyen Cong Thang from HWRU for his great help at any time; Nguyen Thuy Linh from Mekong Committee in Viet Nam for her great support; Prof. Dr. Vu Thanh Ca from Marine Hydro-meteorological Centre for good discussion related to study and other my colleagues for their helps, providing useful information during my study.*

Last but not least, I would like to express my thanks to my family, my husband, my daughter and my parents for their everlasting support and patience.

Thank you all very much, indeed!

Nguyen Thi Thu Huong
IHE Delft, the Netherlands
April 2003

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Chapter 1- INTRODUCTION

1.1 BACKGROUND

Vietnam, as shown in *figure 1.1*, has about 3260 km of coastline stretching along S-shape from latitude 8°N to 22°N and from longitude 105°E to 108°E, which mostly represent low-lying coastal area, having an elevation of one meter or less [Pruszak et al., 2001]. The Nam Dinh province constitutes part of this coastline with the total length of about 70 km and suffering from severe erosion, especially in the Southern part known as Hai Hau coast. In general, the coastline erosion results in serious social and economic consequences of Hai Hau district. Thus, forecasting in advance the coastline change in order to carry out the possible solutions to mitigate the erosion is essential for this area.

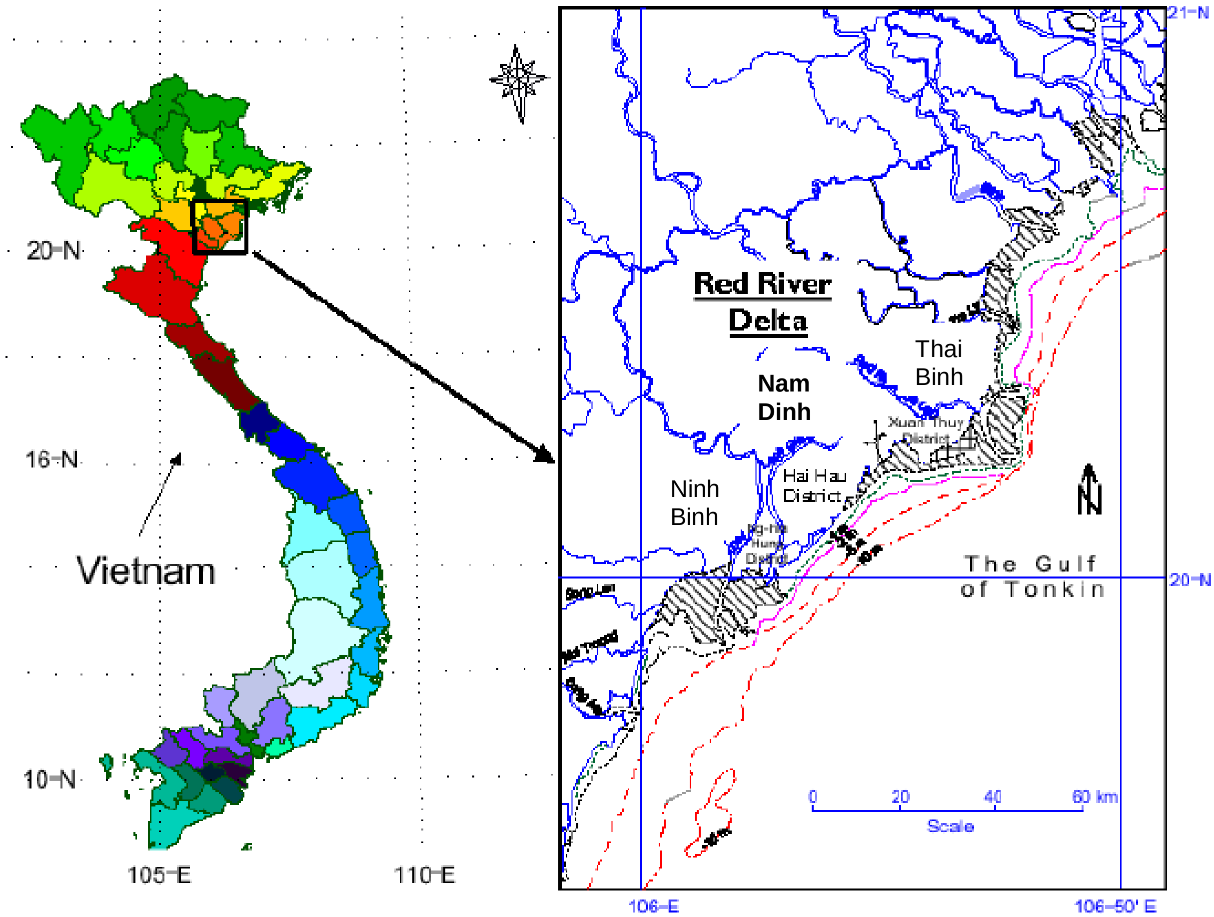


Figure 1-1. Map of Viet Nam indicating the location of the Nam Dinh coastline

[Pruszak et al., 2001]

For this purpose, information on wave conditions in the area of interest is required. To estimate the wave conditions in coastal areas a numerical wave model can be used. In the present study, a wave model (**SWAN**) has been developed for the simulation and prediction of wave in nearshore at Hai Hau coast, in Nam Dinh province.

The ***SWAN** (acronym for **S**imulating **WA**ves **N**earshore)* model was first released in 1997 by Delft University of Technology and since then it has been widely used by many government authorities, research institute and consultants all over the world. The feedback widely indicated the reliability of SWAN in different experiments and field cases. It has therefore been chosen to perform the wave simulation in this project.

1.2 PROBLEM STATEMENT

The erosion problem at Hai Hau coast in Nam Dinh province was investigated by several earlier studies. A difficulty in carrying out such studies is the limited amount of data that is available in the nearshore such as: wind, wave, current,… and sediment transport data. In order to estimate these characteristics along the coast, numerical models are valuable and necessary tools to apply [Hung et al., 2001]. A variety of such models is available in which the sea state at the coastal site is obtained by transforming deep water wave data to the shore. These models can be 1D or 2D depending on the complexity of the condition in coastal area, the required accuracy and of course the availability of the model as well. For Hai Hau coastline, according to one of the previous studies [Bas,W., 2002] it was concluded that applying a 1D wave model for transforming the wave data from deep water to shallow water will result in a negative output of longshore transport compared to the reality. So it can't predict the coastline change adequately. The idea of applying a 2D model to define the wave climate in nearshore from offshore data is initiated to optimise the output for the simulation of coastline change. With this in mind, the 2D wave model SWAN is introduced to undertake the computation wave climate in the coastal site of the study area.

1.3 OBJECTIVE OF STUDY

Considering the above, the study is initiated with the main objective to investigate the nearshore wave climate in Nam Dinh coastline in order to be able to explain erosion problems along the coast.

Former study (Bas, W., 2002) showed that the results of 1D wave model were not able to predict the coast erosion adequately. In this study emphasis will be put on a 2D wave model approach using SWAN. This means that a SWAN model will be set up based on available data including sensitivity analysis and calibration. The model results will be compared with actual sediment transport rates in order to investigate whether the 2D model can predict erosion adequately.

1.4 APPROACH OF STUDY

The approach of this study is structured in the proposed objectives of the investigation concerning the nearshore wave climate at Hai Hau coast in Nam Dinh province. The main thrust of the study involves modelling work using SWAN that was developed by Delft University of Technology. Generally, the following approach forms the methodology in undertaking the overall study:

(i) Collect all possible data about meteorological and oceanography (Winds, waves, tides, water levels, currents,…….)

(ii) Review and analyse all the data collected and pursue further data acquisition where necessary.

(iii) Prepare model set up, schematisation, and boundary conditions for the required model works. Work done in relation to this task could be briefed as below:

- Establish the bottom grid
- Establish the computational grid
- Establish a work plan to perform computation
- Prepare of the SWAN input file for various computations

(iv) Perform computations for sensitivity analysis of the model, analyses the results and calibrate the model. The final model schematisation then is decided.

(v) Perform computation for the wave data set of mean statistic year.

(vi) Perform computations of long shore sediment transport by using the output from the previous step and compare with that from 1D.

(vii) Conclusions and recommendations.

1.5 OUTLINE OF THE REPORT

The present report is organised as follows:

Chapter one contains the introduction. In chapter 2, available data in the study area is reviewed. In chapter 3, shallow water wave prediction model SWAN is introduced. Chapter 4 describes the application of SWAN in Nam Dinh coast. In chapter 5, the sensitivity of SWAN on the spatial resolution, generation mode, and boundary condition is investigated then model calibration is treated. The computation of wave from deep water to the shore in the study area for mean statistic year and sediment transport is performed in chapter 6. Also, the comparison with 1D wave approach is treated in this chapter. Finally, chapter 7 give the conclusions and the recommendations of the report.

Chapter 2- AVAILABLE DATA

2.1 GENERAL

According to Cuong (2001) [8], Nam Dinh province, as indicated in *figure 2-1* spreads in an area of 167,631 hectares, the coastal zone has about 8,000 hectares with 72 km of coastline. This area is divided naturally in 4 large estuaries: the Ba Lat (Red river), Ha Lan (So river), Ninh Co (Ninh Co river) and Day (Day river) estuaries. The above coastline is shared for three coastal districts (GiaoThuy-north, Hai Hau-central and Nghia Hung-south). These three districts are separated by branches of the Red River Delta.

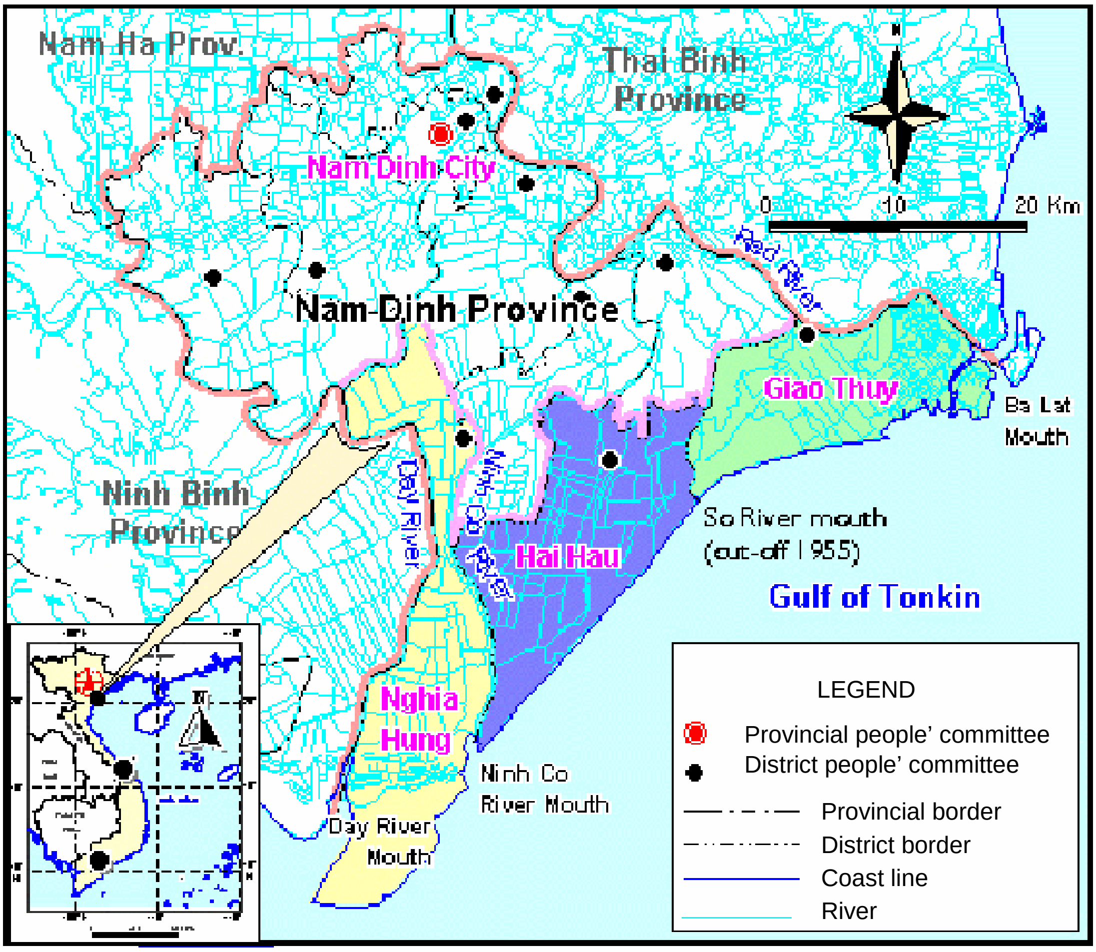


Figure 2-1. Map of Nam Dinh province

Moreover the coastline of Nam Dinh province has a tortuous shape, which changes very often due to erosion and accretion processes present in the area. Every year, in GiaoThuy and Nghia Hung districts, the rivers provide large volumes of deposit of silt, which accretes and enlarges the ground by hundreds of meters. In contrast to that, the coastline of

34 km of Hai Hau district, with an area of 264 km^2, faces severe erosion. It is on the shoreline segment where the study area is located (27.42 km of length).

The complex topography of coastline in Nam Dinh province results in the difficulty and inaccuracy in performing the wave simulation by a 1D model leading to the requirement of a 2D model like SWAN to model the area accurately. The following subsections will review all the available data needed for this study.

2.2 BATHYMETRY

The data for bathymetry was obtained from *WL/Delft Hydraulic* in the Netherlands in spherical co-ordinates in October 2002. It has then been converted into Cartesian co-ordinates for more convenience in coupling with land boundary co-ordinate. A graphical representation of this file is given in *figure 2-2*. In addition, more information about cross-shore profiles are also referred from final report of HE-b1, IHE (2002) [6], they shall be included in *Appendix 2-1 and 2-2*.

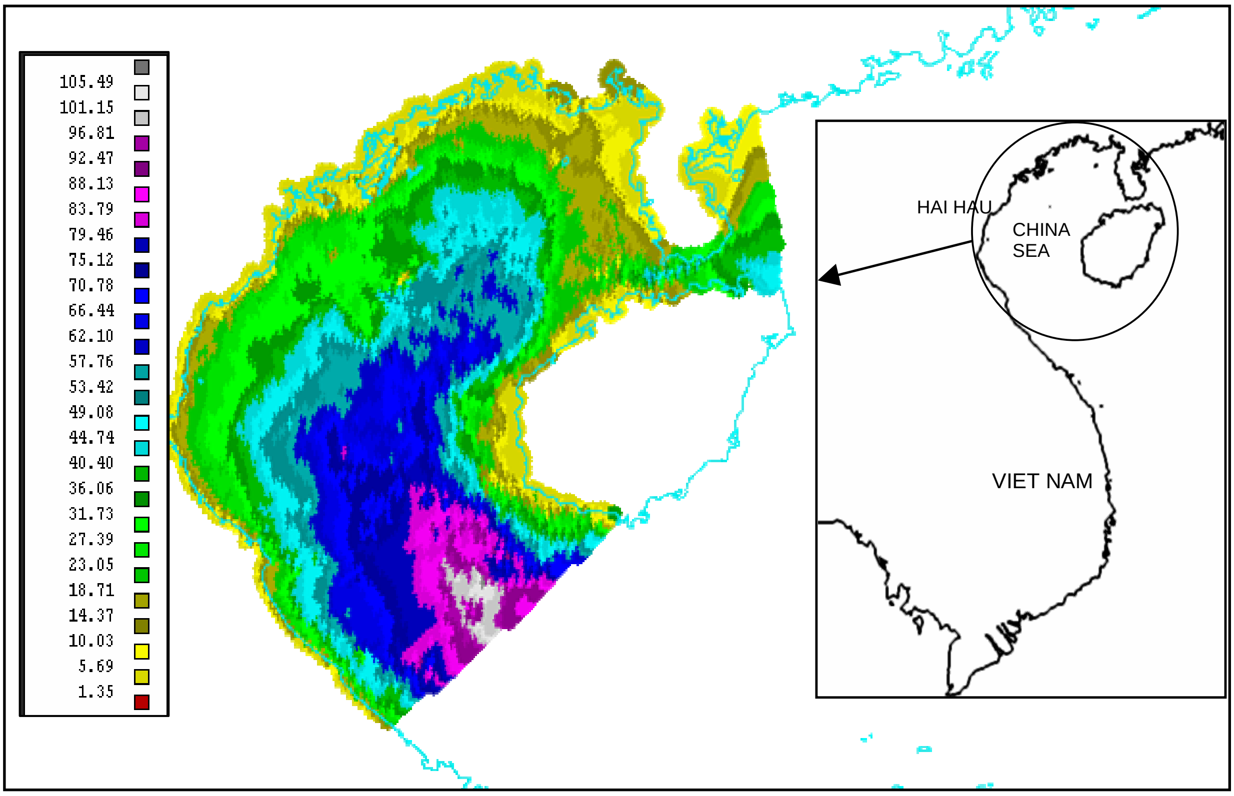


Figure 2-2. Graphical representation of the bathymetry file

[WL/Delft Hydraulic]

2.3 TIDE AND CURRENT

Field observations have showed that the local astronomical tides are of regular diurnal type with the average tidal range of 3÷4m. According to the bathymetry chart, which has the latest version in 1996, at Ba Lat estuary, the mean high water level is +3.51mCD, the mean low water level is of +0.34mCD, and the mean water level is +1.9mCD. From the above data, the water level in the study area can be schematised in *figure 2-3* below.

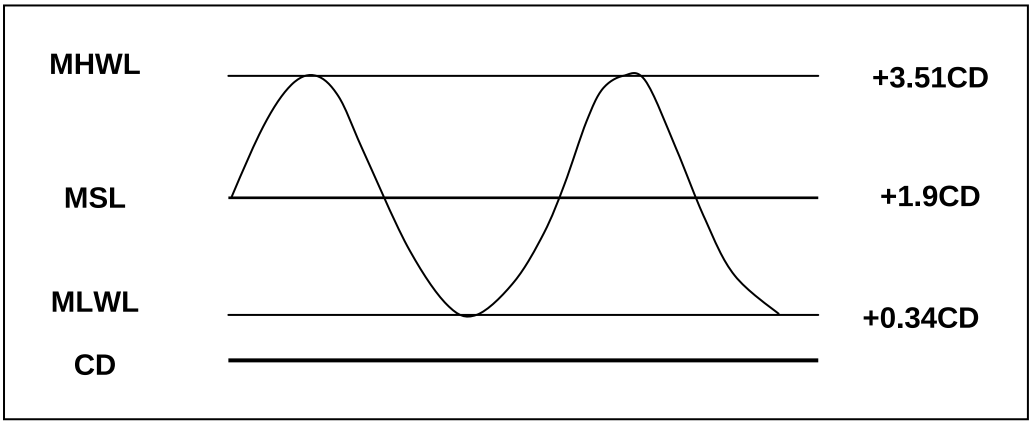


Figure 2-3. Schematisation of water level variation at the study area

In the nearshore area of Hai Hau coastal zone, current system consists of tidal, wave-induced current and wind-induced current. The tidal currents are linked to the flood and ebb tidal circulation. The predominant diurnal tidal flow has a velocity of 25-40cm/s, and its predominant directions in the coastal area are NE during flood tide and SW during ebb tide. The maximum tidal velocity reaches 60-80cm/s. The other major component is littoral currents, which are induced by winds and waves. The average velocity of these currents at Hai Hau coast was found to be about 20-40cm/s under normal conditions. During storms and cyclones, this figure is about 80–100 cm/s or even more. Due to the seasonal wind and wave changes, the predominant littoral current directions also change from season to season, namely they are southward in winter and northward in summer. In winter, the resulting currents are magnified during ebb tide and decrease during the flood tide. In summer, on the contrary, the currents become stronger during flood tide and decrease during the ebb tide. The illustration of longshore current along the coastline of Nam Dinh is given in *figure 2-4*.

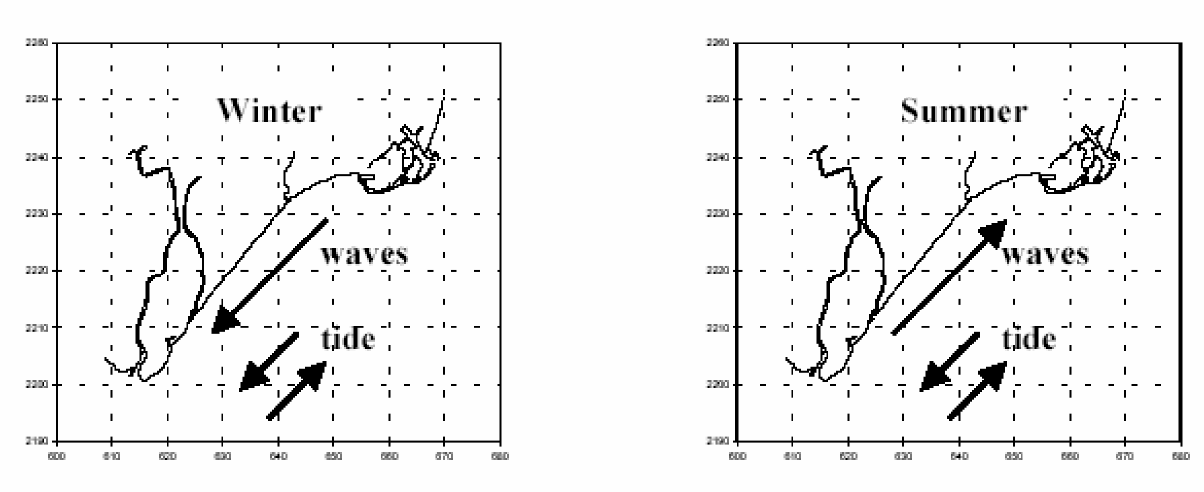


Figure 2-4. Longshore current along the coastline of Nam Dinh in season

2.4 WATER LEVEL

For the time being, measured water level is available for two distinct periods including from 2 to 9, August 2002 and from 2 to 9 January 2003. These data were taken from report of Ninh, P.V., Hung, N.M. (2002) [4]. Measurements were carried out at the station namely LT3 located at Van Ly around the centre of Hai Hau coast. The position of measure station on the map and on cross-shore profile can be seen in *figure 2-5*.

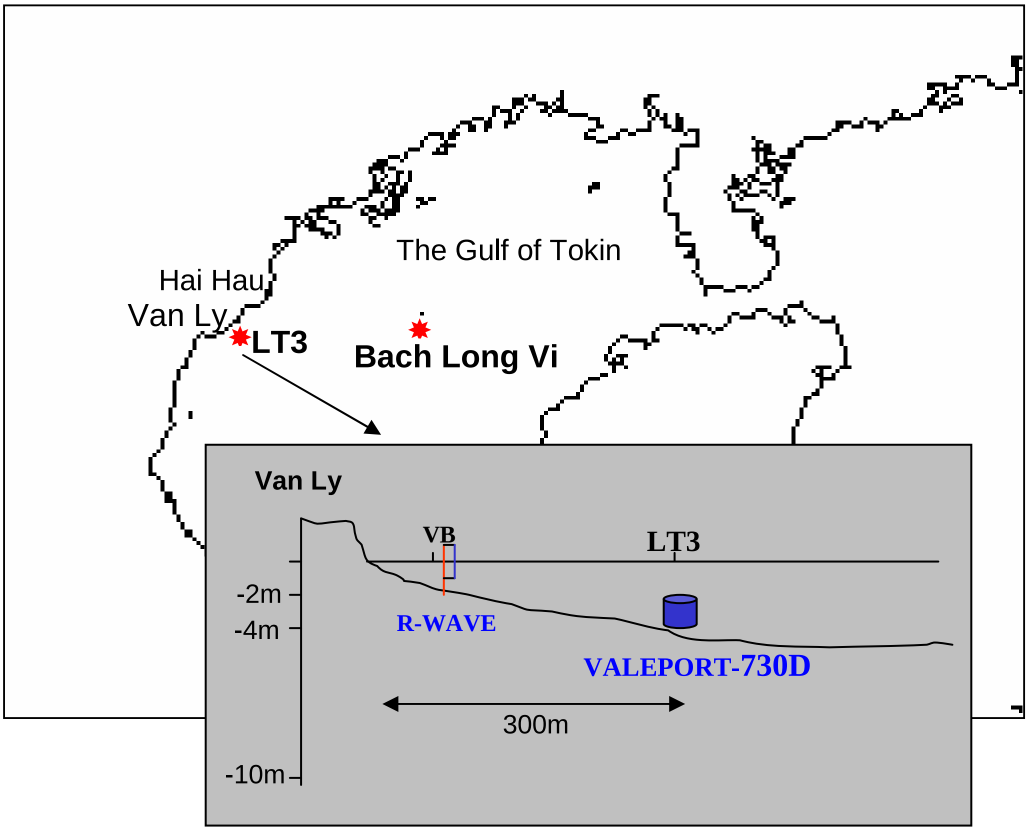


Figure 2-5. Map and cross-shore profile indicating the position of measure stations

Time series plot of recorded water level measurements are shown in *Appendix 2-3*.

2.5 WIND

A meteorological observation post is situated at the rocky island Bach Long Vi in the middle of the Gulf of Tonkin, 150 km far from the shore, at a level 70 meters above sea level. Wind data used in this study was obtained from Hydro-Meteorological Station (HMS) in Viet Nam. Two sets of wind record are available for the study; they include long-term time series and short-term time series data. The long-term record is 20-year time series data of wind observations (every six hours) in the period 1976 to 1995. The short-term record is wind observation from 2 to 9 August 2002 (every 3 hours) and from 2 to 9 January 2003 (every 3 hours). Each set of wind record shall be used for different purpose. Long-term record is used as the requirement to calculate yearly average wave climate that, in principle, has to be based on a minimum of 10-20 years of data to get statistic reliable long-term data. While, short term record is used as the need for model calibration.

Due to the requirement of the model computation, the wind speeds have to be corrected from wind measurement at 70m above sea level to the wind speed at 10m height. This task has been done by the equation 2-1, it is referred from *Shore Protection Manual-Volume1* (SPM, Page 3-26).

$$u(10) = u(z)\left(\frac{10}{z}\right)^{1/7} \tag{2-1}$$

In which:

	u(10)	is wind speed at 10m height (m/s)
	z	is elevation of measurement (m)
	u(z)	is wind speed at elevation z (m/s)

For the long-term time series data, it should be noted that in response to proposed objective, for each coming wind direction, the average wind speed shall be calculated first, the correction of wind speed will be calculated subsequently. In general, the measured wind data for long term has shown that wind blowing to the observation station can be distinguished in 16 directions. Results of corrected average wind speed for each direction of data set for 20-year time series is displayed in *table 2-1*. The illustration of the template of potential wave approach angle band is given in *figure 2-6.*

With regard to short-term time series data, at each particular time point, data of wind direction and wind speed are available. They are all given in *App.5-5 and 5-6*. When employing those data for model simulations, wind speeds will be adjusted to the level at 10m above sea level.

Table 2-1. Average wind speed in 16 directions at Bach Long Vi island

DIRECTION (Deg.N)	348.75 - 11.25	11.25 - 33.75	33.75 - 56.25	56.25 - 78.75	78.75 - 101.25	101.25 - 123.75	123.75 - 146.25	146.25 - 168.75
Mean direction (Deg)	**0**	**22.5**	**45**	**67.5**	**90**	**112.5**	**135**	**157.5**
N^o of observation	1604	3211	7962	1466	3055	971	1850	1415
Average wind speed (m/s) (At 70m height)	3.32	8.86	7.73	5.20	4.33	4.45	4.28	6.88
Average wind speed (m/s) (At 10m height)	**2.51**	**6.70**	**5.85**	**3.94**	**3.28**	**3.37**	**3.24**	**5.21**
DIRECTION (Deg.N)	168.75 - 191.25	191.25 - 213.75	213.75 - 236.25	236.25 - 258.75	258.75 - 281.25	281.25 - 303.75	303.75 - 326.25	326.25 - 348.75
Mean direction (Deg)	**180**	**202.5**	**225**	**247.5**	**270**	**292.5**	**315**	**337.5**
N^o of observation	4922	623	480	89	255	90	311	180
Average wind speed (m/s) (At 70m height)	7.86	6.65	5.11	4.64	3.99	4.46	4.37	5.06
Average wind speed (m/s) (At 10m height)	**5.95**	**5.04**	**3.87**	**3.51**	**3.02**	**3.38**	**3.31**	**3.83**

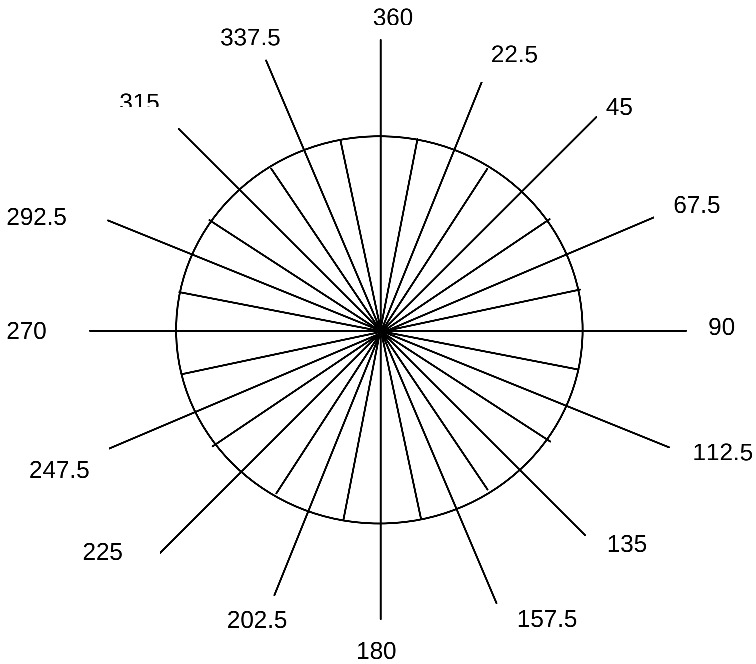


Figure 2-6. Template of potential wave approach angle band (Angle band = 22.5^o)

2.6 WAVES

Extensive amounts of wave data relevant to the present study are available at two locations; they are at Van Ly in nearshore and at Bach Long Vi island in offshore. *Figure 2-5* indicates the position of those stations on the map.

2.6.1 Offshore wave data at Bach Long Vi island

In the Gulf of Tonkin, short wind waves are predominant. They are generated within the limited area of South China Sea. Apparently, the directions of the waves are a result of the monsoon wind directions, e.g. NE in winter and SE in summer [Pruszak, Hung, et al., 2001].

The data set of measured wind speed and direction at Bach Long Vi station was employed to calculate offshore wave parameters for the Nam Dinh area by Hung et al. (2001) [9], using the Svedrup, Munk & Brettschneider wave growth model (SMB method) recommended in Shore Protection Manual (SPM, 1984) [5]. The calculated offshore climate for 20 years (1976-1995, 6-hr interval) were verified using hand-written tables with wave data, based on a 19.5 year record of wave observations in the period from 1962 to 1981 (3 observations per day) at Bach Long Vi island. For more details of SMB method, reference is made to Shore Protection Manual-Volume 1 (1984) [5].

For the long-term wave data, the results of wave conditions at Bach Long Vi have been then classified and tabulated to display the calculated frequency of occurrences for wave heights and wave periods with respect to direction. For more detailed of the wave information, reference is made to *Appendix 2-4*.

For short-term wave data in two time interval 2-9/8/2002 and 2-9/1/2003, the calculated results from SMB method along with measured wind data is given in *Appendix 2-5 and 2-6*

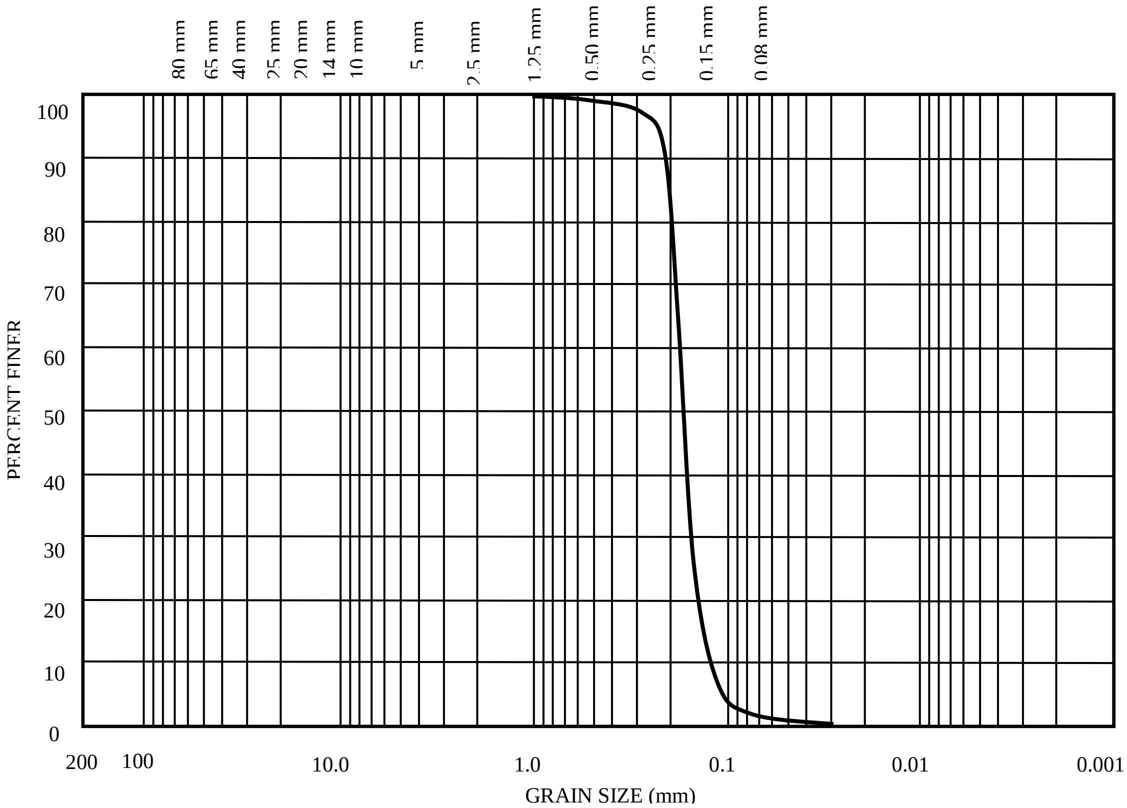
2.6.2 Nearshore wave data at Van Ly

A pressure transducer named VALRPORT-730D, positioned in water, 60cm above seabed, carried out measurements of nearshore wave climate at LT3 station. Measured nearshore wave climate available for two distinct periods from 2 to 9, August 2002 and from 2 to 9 January 2003 were taken from report of Ninh, P. V., Hung, N.M., 2002 [4]. These two periods represent for two typical seasons in the study area, they are summer monsoon (From May to September) and winter monsoon (From October to April). Measurements were carried out at station namely LT3 at Van Ly which is located around centre of Hai Hau coast. Actually, this location was already known as the water level measure point mentioned in section 2.4. The available database for measured nearshore wave climate is similar to that of measured water level. For details of measured wave parameters for two periods, the reader is referred to *Appendix 2-7.*

2.7 SEDIMENT

Particle size distribution at Hai Hau coast is referred from Hung et al. (2001) [9] as shown in *figure 2-7.*

SEA DYKE ENGINEERING SERVICES



Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
1	0.0	0.0	98.0	2.0	

LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_C	C_U
		0.199	0.167	0.157	0.138	0.121	0.113	1.01	1.5

Figure 2-7. Sieve curve of beach material in Hai Hau coast, Nam Dinh province

A general scheme of sediment flux showing the rate of sediment discharge to the sea by the main Red River Delta branches together with the division of the coastline area into three parts is presented in the attached *figure 2-8.*

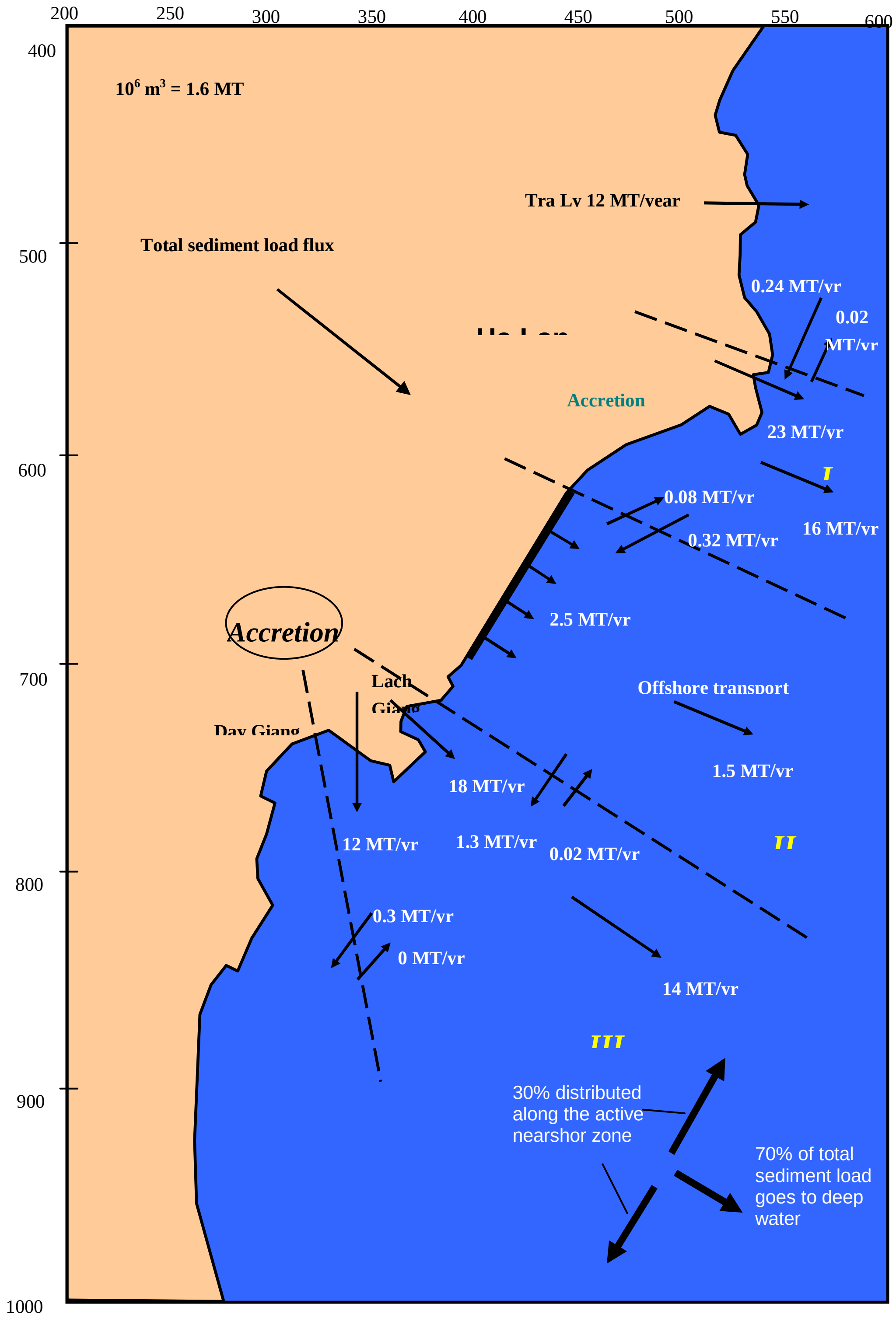


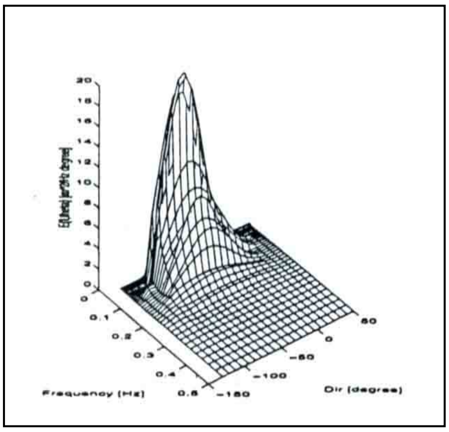
Figure 2-8. Sediment budget in Hai Hau coast, Nam Dinh province

Chapter 3- NUMERICAL WAVE MODEL SWAN

3.1 BACKGROUND OF WAVE SPECTRA

3.1.1 Wave energy spectra

Due to the chaotic nature of waves a description of wave in time domain is rather difficult. An alternative is the description of waves in spectral domain, which enables a ready interpretation with linear wave theory. The spectra analysis decomposes the chaotic ocean waves into harmonic waves having different amplitudes, frequencies and directions. Then it is possible to represent the sea surface elevation as a function of time t and horizontal co-ordinate x-y, the result is two dimensional spectrum *(See figure 3-1)*. Two-dimensional spectrum is a summation of a large number of harmonic wave components with different amplitudes, frequencies and directions. The physics of these harmonic waves is thus known within the linear wave theory. Typical two-dimensional spectrum could be characterised by wave parameters such as significant wave height (H_s), mean wave period (T_{mo}) and peak wave period (T_p). Integration of a two-dimensional spectrum with respect to direction results in one-dimensional spectrum giving the variation of energy against frequency *(See figure 3-2)*.



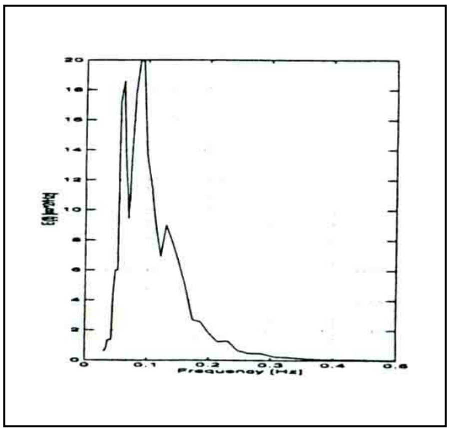


Figure 3-1. 2D wave energy spectrum **Figure 3-2. 1D wave energy spectrum**

3.1.2 Spectral wave parameters

Spectral wave parameters are expressed as moments of the energy density function *E(f)*. If the n^{th} momentum of the spectrum is m_n, it could be expressed as:

$$m_n = \int_0^\infty f^n E(f) df \qquad (3\text{-}1)$$

With these moments some commonly applied wave parameters are described:

- Significant wave height: $H_s = 4\sqrt{m_o}$ (3-2)
- Mean wave period: $T_{m01} = m_0/m_1$ and $T_{m02} = \sqrt{m_0 / m_2}$ (3-3)
- Peak wave period: $T_p = 1/f_p$ (3-4)

(Period corresponding to maximum energy density)

- Mean wave direction: $DIR = \arctan\left[\dfrac{\int \sin(\theta)E(\sigma,\theta)d\sigma d\theta}{\int \cos(\theta)E(\sigma,\theta)d\sigma d\theta}\right]$ (3-5)

3.2 BASIC EQUATION IN SWAN

In SWAN the waves are described with the two-dimensional wave action density spectrum. The evolution of this spectrum for Cartesian co-ordinate is:

$$\frac{\partial}{\partial t}N(\sigma,\theta) + \frac{\partial}{\partial x}c_x N(\sigma,\theta) + \frac{\partial}{\partial y}c_y N(\sigma,\theta) + \frac{\partial}{\partial \sigma}c_\sigma N(\sigma,\theta) + \frac{\partial}{\partial \theta}c_\theta N(\sigma,\theta) = \frac{S(\sigma,\theta)}{\sigma} \quad (3\text{-}6)$$

- The term σ and θ denotes the relative frequency and direction respectively.

- The term $N(\sigma,\theta)$ denoting the action density of wave, is the ratio of the energy density $E(\sigma,\theta)$ and the relative frequency σ.

- The term c_x, c_y, c_σ and c_θ represent the energy transport velocity (including the effect of current) in the geographical space (x,y) and the spectral space (σ,θ) respectively.

- Different terms in the action balance equation could be briefed as follows: From the left

Term (1) represents the local rate of change of action density in time.

Term (2) and *term (3)* represent the propagation of action in geographical space (with propagation velocity c_x and c_y).

Term (4) represents the shifting of the relative frequency due to the variation of depth and current (with a propagation velocity c_σ in σ space).

Term (5) represents depth-induced and current–induced refraction (with propagation velocity c_θ in θ space).

Term (6) on the right hand side of the balance equation is the source term in term of energy density representing the effects of generation, dissipation and non-linear wave-wave interactions. This source term could be expressed as the sum of the separate physical processes given by *(3-7)*.

$$S(\sigma,\theta) = S_{in}(\sigma,\theta) + S_{nl}(\sigma,\theta) + S_{ds}(\sigma,\theta) \quad (3\text{-}7)$$

Where: $S_{in}(\sigma,\theta)$ – Generation of wave energy by wind

$S_{nl}(\sigma,\theta)$ – Transfer wave energy due to non-linear wave-wave interaction

$S_{ds}(\sigma,\theta)$ – Dissipation wave energy due to bottom friction, white capping and wave breaking.

SWAN computes the variations of energy density by integrating the source terms (i.e. taking into account the local effects like wind, white capping, wave-wave interaction, effects of bottom and currents) and simultaneously propagating this quantity at group velocity on a regular rectangular grid.

This report does not include a description of the formulations used in the various terms in the model equations. Reference is made to Ris, R.C (1997) for the descriptions of these aspects.

It should be noted that wind generation, wave-wave interaction and white capping control the evolution of wave energy spectra in the presence of a wind field. Evolution of the spectrum in a standard field was first observed by Hasselmann et al. (1973) in the **JONSWAP** project *(**JO**int **N**orth **S**ea **WA**ve **P**roject)*, hence this spectrum was named as a JONSWAP spectrum. In practice, the JONSWAP spectrum is considered as the design wave spectrum for deep water. *Figure 3-3* indicates the influence of wave related phenomenon on a typical JONSWAP type spectrum.

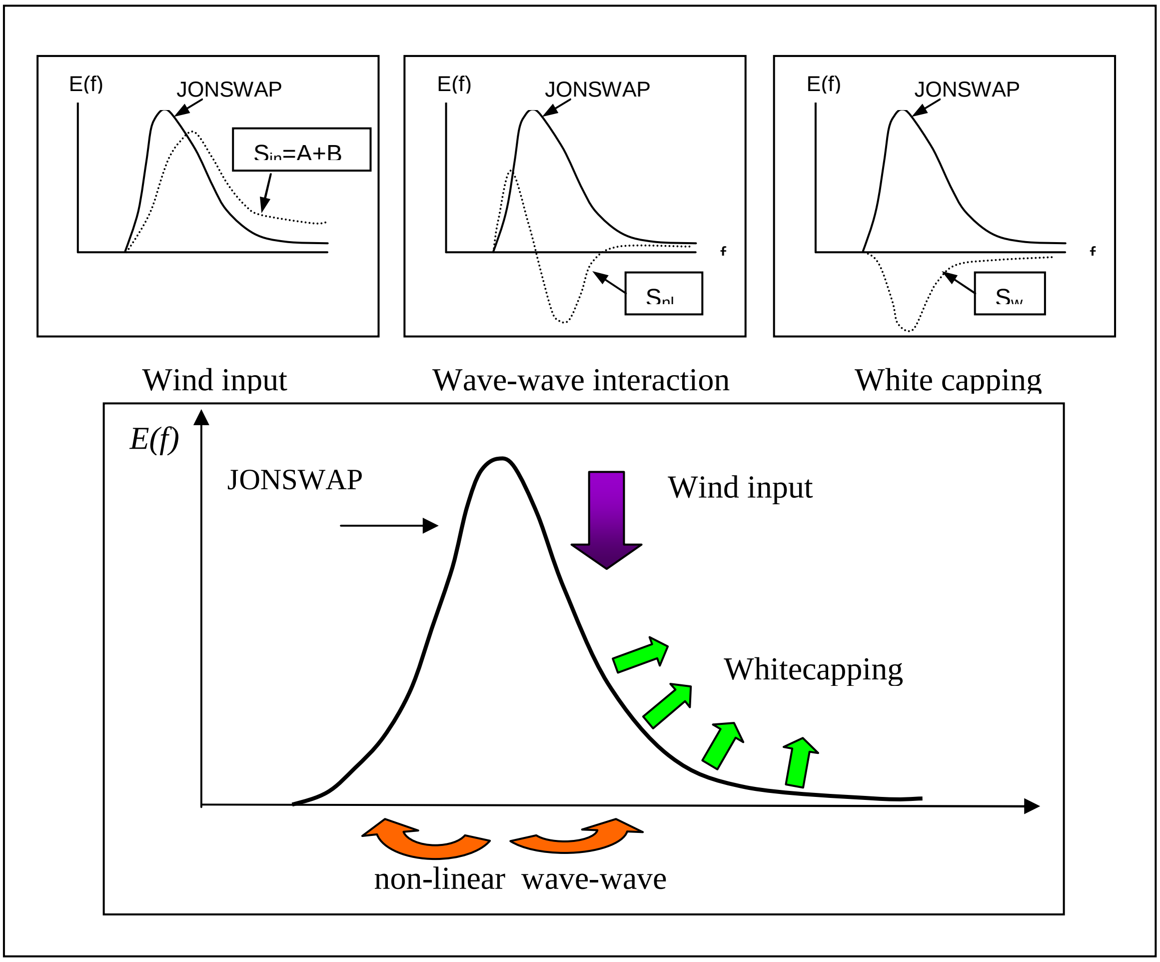


Figure 3-3. The flow of energy through a JONSWAP spectrum

3.3 GENERATION MODE

Numerical wave models have been categorised into first, second and third generation models, on the basis of the level of parameterisations of the source term.

The following table briefs the available options in SWAN for the source terms in different generation modes.

Table 3-1. Expression for Source Terms in SWAN

Source terms	Expression	Generation mode of SWAN		
		1st	2nd	3rd
Linear wind growth	*Cavaleri & Malanotte-Rizzoli (1981)* [Modified]	x	x	
	Cavaleri & Malanotte-Rizzoli (1981)			x
Exponential wind growth	*Snyder et al. (1981)* [Modified]	x	x	
	Snyder et al. (1981)			x
	Jassen (1989, 1991)			x
White capping	*Holthuijsen and De Boer (1988)*	x	x	
	Komen et al. (1984)			x
	Jassen (1991), Komen et al. (19940			x
Quadruplet interactions	*Hasselmann et al. (1985)*			x
Triad interactions	*Eldeberky (1996)*	x	x	x
Depth-induced breaking	*Battjes & Jassen (1978) with Nelson (1994)*	x	x	x
Bottom friction	*Hasselmann et al. JONSWAP (1973)*	x	x	x
	Collins (1972)	x	x	x
	Madsen et al. (1988)	x	x	x
Obstacle transmission	*Seelig (1979)*	x	x	x

3.4 MODEL IMPLEMENTATION

3.4.1 Co-ordinate system in SWAN

In order to perform the wave computation model accurately, it is essential to have clear picture of the basic co-ordinate applied in a numerical model. In SWAN, two co-ordinate systems must be selected to set up the model.

<u>Co-ordinate systems for geographical locations</u>

In SWAN all geographical locations can be defined in the so-called *problem co-ordinate system* according to the two following co-ordinate systems:

- **CARTESIAN:** All locations and distances are in m. Co-ordinate is given with respect to x and y axes chosen arbitrarily by the user.

- **SPHERICAL:** All co-ordinates of locations and geographical grid sizes are given in degrees, x is longitude and y is latitude. Input and output grids have to be oriented with their x-axis to the East, mesh sizes are in degrees. All other distances are in m.

Co-ordinate systems for the directions of winds and waves

There are two options for the convention of the directions of winds and waves in SWAN, they are:

- The **CARTESIAN convention:** The direction to where the vector points, measured counter clockwise from the positive x-axis of this system (in ^{o}).
- The **NAUTICAL convention:** The direction where the wind or the wave comes from, measured clockwise from geographic North.

3.4.2 Grid system in SWAN

The grid used in SWAN model may be either curvilinear or rectangular grid. Three grids should be defined in SWAN computations are mentioned below.

Input grid

Input grid is a grid on which the bathymetry, current, water level, friction coefficients and wind field are defined. Input grids can be different from each other, both in dimension and orientation. The spatial resolution of the input grid depends on the accuracy of the spatial details required. Users should chose the spatial resolutions for those input grids in such way that the relevant spatial details are properly resolved and special care is required in extremely complex coastal area and estuary. However, it should be noted that smaller resolution, more accurate the results will be, but at the same time the required computer space will be increased.

Computational grid

Computational grid is a grid on which model solves action balance equation. In SWAN, users can decide the orientation (direction), the dimension and the resolution of computational grid system, which include the geographical and spectral grids. These two grids can be defined independent from each other.

- ***Geographical grid***

Geographical grid describes the orientation, dimension and the resolution of the area in which wave computation are to be performed. Generally, three types of grid can be used: a regular rectangular grid (Δx=constant, Δy=constant), an irregular rectangular grid (Δx=variable, Δy=variable) and a curvilinear grid. For the situation in which a higher grid resolution is locally required, grid nesting is optionally available in the SWAN model. In this nesting option the computations are carried out on a coarse grid for a higher area and subsequently on a finer grid for a smaller area. The boundary conditions for the finer grid are obtained from the coarse grid.

The *x, y* resolution and the orientation of the computational grid is defined by the user. The spatial resolution of the computational grid should be selected in such a way that it is sufficient to solve relevant details of the applied wave field. Better results could be obtained by taking the resolution of the computational grid and the input grid approximately equal, by doing such a way the error due to interpolation between grids could be minimised.

In principle the input grid should cover the larger area the computational grid both in space and time. If for some reasons the computational grid exceeds the dimensions of an input, for region outside the input grid, SWAN assumes that the particular parameter is identical to the value closer to the boundary.

In addition to the computational grid in geographical space, SWAN calculates also wave propagation in spectral space. To that end for each geographical grid the spectral grid has to be specified as explained below.

- ***Spectral grid:*** The spectra grid consists of the frequency space and directional grid.

- *Frequency space*

In frequency space, it is simply defined by a minimum and maximum frequency and the frequency resolution is proportional to the frequency itself (common is $\Delta f=0.1f$).

- *Directional space*

In directional space, usually the directional range is the full 360^o unless when wave travel towards a coast within a limited sector of 180^o, it is convenient (less computer time and/or space) to specify the limited directional range. The directional resolution is determined by the number of discrete directions provided by the user. *Table 3-2* contains the discretization for each type of grids recommended by the SWAN developers.

Table 3-2. Recommended discretizations for spectral grid

Directional resolution for wind sea conditions	$\Delta\theta = 10^o$-15^o
Directional resolution for swell sea conditions	$\Delta\theta = 2^o$-5^o
Frequency range	$\sigma_{min} = 0.04$ Hz
	$\sigma_{max} = 1.00$ Hz
Spatial resolution	$\Delta x, \Delta y$ = 50-1000m

Output grid

SWAN can provide outputs on spatial grids that are independent from input grids and computational grids. An output grid has to be specified by the user with care since different in grid resolution among these three grid systems could result in inaccuracies due to interpolation errors. Thus it is wise to keep three grid systems identical, if possible.

3.4.3 Boundary conditions

It is essential to define the boundary conditions both in the geographical and spectral space to facilitate the integration process of the action balance equation.

Boundary conditions in the geographical space

There are some of the important aspects that should be taken into consideration when deciding the orientation, extent and the resolution of geographical grid system. The orientation of the grid can be chosen arbitrary; the boundaries of the computational grid in SWAN are either land or water. In case of land there is no problem. The land does not generate waves and in SWAN it absorbs all coming wave energy. But in the case of a water boundary there is a problem. If no wave conditions are known along such a boundary, SWAN then assumes that no waves enter the area and that waves can leave the area freely. This assumption obviously contains errors, which propagate into the model. If the observations are available, they can be used as input at the boundary. However, this usually covers only part of boundaries so that rest of the boundaries suffer from same errors as above. For these reasons, the lateral boundary must be chosen sufficiently far away from the area where reliable computation are needed so that they do not affect the computation result there. This is not the case if the wave condition along the lateral boundaries are specified in segment by the user or such problem occur obviously not if the lateral boundary contain wave information over their entire length, for example, obtained from a previous SWAN.

Boundary conditions in spectral space

In frequency space the boundaries are fully absorbing at the lowest and highest discrete frequency facilitating wave energy can freely propagate across these boundaries. Since the directional space is a closed circular space, no boundary conditions are needed if the full circle is used. For the reason of economy it is also possible to define directional sectors instead of a full circle. In such cases the boundaries of these sectors are fully absorbing. Therefore action density travelling outside this pre-defined sector will be removed from the model.

Chapter 4

THE APPLICATION OF SWAN IN NAMDINH COAST

This chapter deals with the application of SWAN in the particular case in Nam Dinh coast. The purpose is to investigate and optimise the representation of some elements for the study case. Basically, it contains a description of the overall model settings, applied model schematisation, selection of the boundary to be modelled and work plan adopted to perform computations.

4.1 OVERALL MODEL SETTINGS

In this assignment, calculations have been carried out with the latest version SWAN 40.11. In all computations the standard settings were used for the physical processes. For more details of the model setting, the reference is made to SWAN implementation manual [1]. However for the aim of completeness, they are briefed in *table 4-1.* Also, the selection of generation mode, stationary/non-stationary mode, the effect of current, wind condition and the accuracy criterion among the available options are indicated in *table 4-1*. The explanation how to choose such options are descried hereafter in the coming subsections.

Table 4-1. The default settings in SWAN and selection for model setting

	Option	Description
Physical process	Wind input	Third generation according to Komen et al. (1984). Default coefficients.
	White capping	Komen (1984). Default coefficients.
	Quadruplets	Default coefficients.
	Depth induced wave breaking	The bore-based model of Battjes and Janssen (1978). Default coefficients.
	Bottom friction	JONSWAP. Default value.
	Triads	Default coefficients.
Generation	GEN3	See table 3-1
	GEN2	See table 3-1
Stationary/non-stationary mode	Stationary mode	Variable time is removed from the action balance equation 3-6
Current effect	Absence of current effect	No input grid for current
Accuracy command	Standard accuracy criterion	Drel=2%, dHabs=0.02m, dTabs=0.02s, Npnts=98%, Nmax=15iterations
Wind condition		Uniform wind condition in computational grid

4.1.1 Generation mode

As described in *chapter 2*, short wind wave is predominant in the study area. Therefore, to satisfy for properly describing wind seas the quadruplet wave interaction should be taken into account. For that reason use of the wave prediction models in third generation mode (GEN3) is the best option from a point of view of quality in this particular case. But the price is that an enormous computation effort and much more time is likely to be expected. In addition, using third generation mode it is even hard to converge for the final solution with the standard accuracy criterion. In order to solve this problem, there are two solutions can be done. First, the choice of GEN2 mode may be a substitute option, but then its characteristic computation has to be verified with the GEN3 option. In this way, the users can see how good the GEN2 option works in their cases. The second solution is relaxing the accuracy criterion such that model can converge to final solution but the results are still reliable. In the situation presented here, final selection will be made after comparing the results from GEN2 and results from GEN3 mode. This task will be undertaken in *chapter 5*.

In short, command GEN2 **or** GEN3 combination with TRIAD, BREAK and FRIC will be activated in command file to represent the physical processes for the study. The default SWAN settings have been adopted for all physical processes, they are briefed in *table 4-1*.

4.1.2 Stationary mode

To achieve a computationally feasible wave model for this particular case of coastal applications, the independent variable time has been removed from the action balance *equation 3-6* to make the *model stationary*. This is considered acceptable for most coastal applications since the residence time of the waves in the computational area is expected to be far less than the time scale of variations of the wave boundary condition, the ambient current, the wind or the tide. The option ***STAT*** (stationary) in command MODE in SWAN command file has been chosen for all SWAN runs in the present study.

4.1.3 Current effect

The effect of current on wave propagation (current induced shoaling and refraction) can be significant in the coastal area near the estuary where the current velocity is expected to be significant (velocity in the order of a few meters per second) and dramatically change the wave condition. In this study, the situation is decided to be characterised with the ***absence of currents*** due to first the information on currents in the study area is not sufficient to perform a model computation. Secondly, the study area is recorded that the current speed is generally < 1m/s (see *chapter 2*), this current may only change the wave condition with small rate (about 10% in the area of 10m depth), thus neglect the effect of current is considered acceptable.

4.1.4 Wind condition

In this study, wind condition (wind speed and wind direction) is assumed to be uniform in the entire computational grid and the same as the wind condition at boundary in deep-water region. It should be noted that the wind field should be defined differently in each grid point of the input grid. However this procedure requires more detailed data and also the effort to adjust the wind data from the observation point to all grid point. In the case considered here, since no information were available of the spatial variations of the wind field, so the wind measured at Bach Long Vi island is taken as the constant wind condition in the computational grid.

4.1.5 Accuracy criterion

As described in SWAN implementation manual [1] the computations in SWAN are carried out by an iterative four-sweep technique, which is terminated by a user based on accuracy criterion. At present, the following criteria are adopted in this study: The iteration is terminated when in more than *98%* of the water covered grid points the change in significant wave height H_s between two successive iteration is less than *2% or 0.02m* and the change in mean wave period T_{m0} between two successive iteration is less than *2% or 0.2s*. Experience with the SWAN model has shown that these conditions seem to be accurate enough in practical coastal applications.

4.2 MODEL SCHEMATIZATION

Although SWAN program can be easily accessible through INTERNET, it is still not developed enough to categorise as user-friend package. Therefore when applying SWAN to particular case study, it is essential to familiarise with some other softwares to carry out pre and post processing of SWAN (e.g. ARC_VIEW and ARC_INFOR), these programs are helpful in terms of visualisation for the input and output data. In addition to that, in order to set up the grid for the model, two packages in Delft3D (From WL/Delft Hydraulic) have been used in the present study as well, they are RGFGRID and QUICKIN. Due to the time limited, this report will not go in detail about those programs, instead this section will only describe the obtained schematisation for model simulations in *chapter 5 and 6*.

4.2.1 Co-ordinate system

The SWAN model presented here is formulated in ***Cartesian co-ordinates*** (a flat plane), which is acceptable considering the spatial scale of coastal areas. The geographical origin is referred from the co-ordinate of land boundary that is downloaded in the Internet system.

The direction of winds and waves are defined in the present model according **to *Nautical convention***, it was described in *chapter 3* that the direction where the wind or the waves come from is measured clockwise from the geographic North.

4.2.2 Grid system

In SWAN, users can decide the orientation (direction), extent and the resolution of input grid, computational grid system, and output grids. These three grids can be defined independently from each other. Firstly, the position, orientation and the extent of these grids need to be defined, then the resolution will be considered.

The orientation and extent of grid

The position and orientation of grid affect the degree of efficiency and accuracy of the model computation for the interested area. The final decision should be made based on the consideration between different alternatives, which are formulated on the basis of measured station. In this particular case, the observation post is situated at Bach Long Vi Island, 150 km far from Nam Dinh coast, in the China sea. This position of the observation post initiated the idea of three alternatives for the position and orientation of grid. Details of files and graphical representations for those alternatives are given in *table 4-2* and *figure 4-1*, respectively.

Table 4-2. Details of three alternatives for position and orientation of grid

NAME	TYPE	ORIGIN OF GRID		LENGTH		ORIENTATION
		Xo (m)	*Yo (m)*	*Lx (m)*	*Ly (m)*	*(Degr)(Car)*
AL1	Curvilinear	See figure	See figure	See figure	See figure	See figure
AL2	Rectangular	677784	1898920	600000	300000	45
AL3	Rectangular	591827	2036489	500000	150000	45

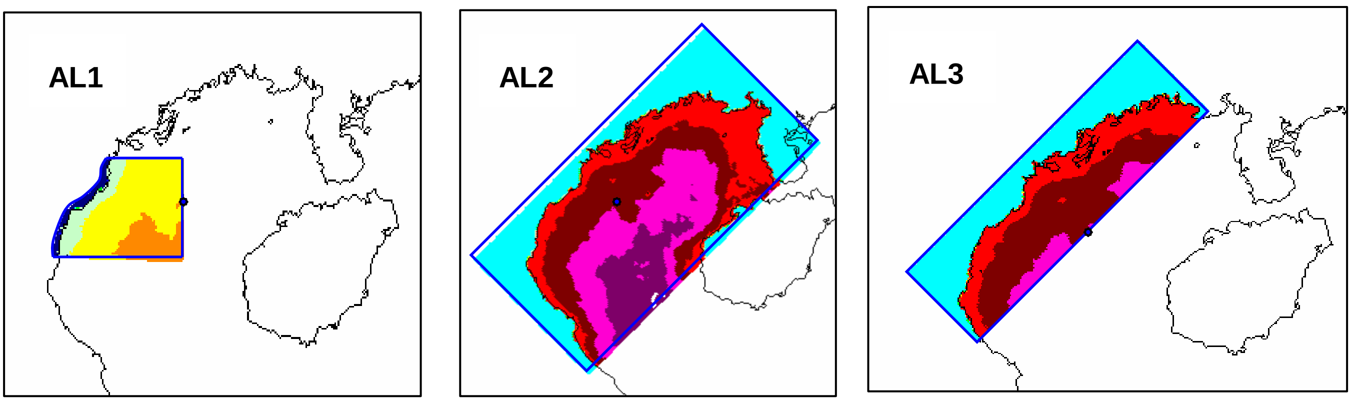


Figure 4-1. The illustration of different computational grids

Among these grids, the most reasonable one should be selected so that the resolutions and other conditions could then be performed properly on it for the further steps. Analysis of the advantage and disadvantage for each grid is given below. The final decision has subsequently been made to achieve one grid for future computations.

AL1 grid: This small curvilinear grid has three lateral boundaries with one of them going through the observation point. The available wave data at the measure point can be used as constant in the East side boundary. With respect to two other boundaries, no wave information is known and SWAN will assume that no waves enter the area and that waves can leave the area freely. This assumption obviously contains errors that propagate into the model. This grid is considered acceptable only when the mean wave direction is from Eastern ward since the area of interest would not be affected by those errors (For the explanation, reference is made to SWAN implementation manual [1]). Or in case that computation is carried out in only one direction of mean wave, this option can be applied by adjusting the orientation of grid so that the mean wave direction is normal to the open boundary. However, as the scope of this study is to calculate the near shore wave condition for the data set of the mean statistical year, it implies that the wave would come from many directions, thus in other directions the study area may be influenced by the errors from no-wave condition boundaries. For that reason, this grid has been sorted out of the selected option.

AL2 grid: This is a rectangular grid with the size covers all the Gulf of Tokin so that only two segments in east side are open boundaries with no wave information on it. The reason to create such grid is that although the wave conditions at boundary is unknown, but we can use the "try and error" method to put wave conditions at the boundary until the wave condition at Bach Long Vi island obtained from the model corresponds well with the available data. With this grid, the results from the model for the study area is considered as precise, but in turn it takes time for each wave condition computation due to the scale of grid and also due to trial and error method. As a result, the time required for computation of all wave data will be quite long. Due to those reasons, this grid has not been selected for the present study as well.

AL3 grid: The final grid considered here is the rectangular grid that covers the Nam Dinh coast and extend till Bach Long Vi island in Eastern ward and till land in the Northern and Southern direction. The orientation of the grid is rotated in such a way that the offshore boundary more or less parallels with the depth contour in the study area. This will allow a uniform approach of deep-water waves into the computational grid. The advantage of this grid is that it has only one open boundary going through the observation point, thus available data can be used and error entering the model is less. The result at the study area is expected to be accurate and the computation time is shorter compared with the previously considered grid.

❖ Considering the above analyses, it can be concluded that the ***alternative AL3*** seems to suggest the most reasonable grid and therefore will be adopted in this particular case for all the input, computational and output grids. *Figure 4-2* illustrates the land boundary and grid adopted for this study.

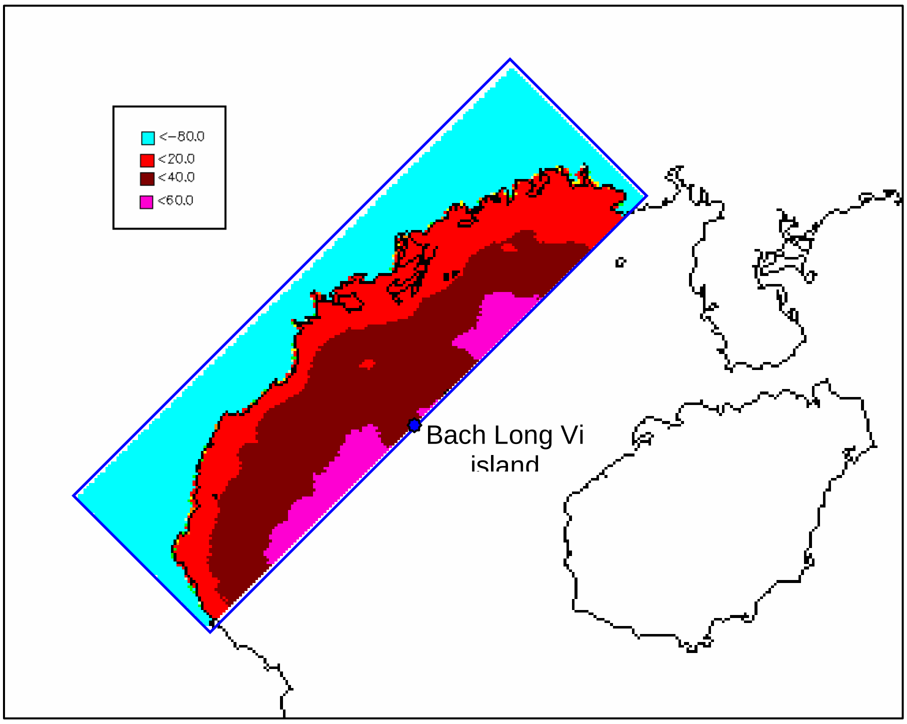


Figure 4-2. The illustration of land boundary and extent of grid

<u>Geographical grid</u>

- ***Input grid***

An important aspect in numerical wave modelling is generating a bottom schematisation as accurate as possible. A bottom grid with very fine resolution may generate better model prediction but it also consumes large amount of computer time and effort. Therefore, it is important to take both these facts into account when selecting the resolution of the bottom grid.

In this study, from the bathymetry file provided by WL/Delft Hydraulic and the selected grid extent, the input grid with resolution of Δx=1000m and Δy=1000m is adopted and it is considered acceptable to represent the sea bottom of the study area. *Table 4-3* gives the detail descriptions of the input grid.

Table 4-3. The bottom grid applied in Nam Dinh coast

Xo(m)	Yo(m)	Lx(m)	Ly(m)	Δx(m)	Δy(m)	α (°) (Car)
591827	2036490	500000	150000	1000	1000	45

- ***Computational grid***

In SWAN it is best to select the computational grid identical with the input grid so that no interpolation errors occur. However, in this case if do so the required memory for model computation is too large (This value is estimated by the formula: mxc*myc*msc*mdc=500*150*36*31=83.700.000 - Formula is referred from SWAN implementation manual - Page 44). With this required memory, time needed for each test case is quite long (about 4 hours). For practical applications and to some extent for scientific investigations, this option seems to be not realistic for the application of the current study. In addition, similar to the remarks mentioned for input grid, the resolution of the computational grid decides both the accuracy and the time required for computation, so to achieve the optimal alternative for resolution of the computational grid, a possible method is to generate several grids in different resolutions. Then the result is compared with measured data so that the option with the best agreement between accuracy and time consuming is obtained. In this study, four computational grids have been proposed and investigated (Including the alternative of nesting grid), the descriptions of them are given in *table 4-4*. The sensitivity analysis of the model with respect to resolution of grid is described in *chapter 5*.

Table 4-4. Description of spatial computational grids

Grid	Xo(m)	Yo(m)	Lx(m)	Ly(m)	Δx(m)	Δy(m)	α(°)(Car)
C1	591827	2036490	501000	150000	3000	3000	45
C2	591827	2036490	500000	150000	2000	2000	45
C3	591827	2036490	500000	150000	1000	1000	45
C4(Nest)	630009	2180741	91000	48000	500	500	45

- ***Output grid***

The output grid is adopted to be identical to the computational grid, in this way no interpolation error occurs from the computational grid to output grid. However, output at pre-specified points are still affected by error from interpolation procedure and these errors are obviously different among a variety of computational grids.

Spectral grid

Spectral grid consists of a frequency grid and a directional grid. According to recommendation of the SWAN implementation manual as described in *chapter 3*, the spectral grid has been selected and given in *table 4-5*.

Table 4-5. Description of the basic spectral grid

	f_{low} (Hz)	f_{high} (Hz)	Msc	$\Delta f/f$	CIRCLE or SECTOR	Mdc	$\Delta\theta$
Frequency grid	0.05	1.00	31	0.1	--	--	--
Direction grid	--	--	--	--	CIRCLE	360	10

4.3 BOUNDARY CONDITIONS

To perform numerical computation with the SWAN model, wind and wave boundary conditions are required. In this assignment, three types of boundary condition can be distinguished, they shall include the boundary condition for sensitivity investigation, set of boundary for model calibration and boundary conditions for model application of entire early average wave data. These input data are to be described in details as below.

4.3.1 Boundary conditions for sensitivity analysis

In *chapter 5* the sensitivity analysis of SWAN will be investigated, it is thus necessary to adopt a number of fixed boundary conditions for that task. Because of that reason, hereafter two boundary conditions are called from the measured data set as main boundary conditions to investigate the sensitivity of SWAN. The wave conditions in deep water, the wind velocity and wind direction as well as the mean water level are listed in *table 4-6*.

Table 4-6. Boundary conditions for sensitivity analysis

Bound N°	Measured time point	Water level	Wind condition		Offshore wave condition		
			U_{10} (m/s)	*Dir (Nau.deg)*	H_s (m)	T_p (s)	*Dir (Nau.deg)*
1	6/8/02 16:00	1.0 MSL	5.3	203	0.9	4	203
2	4/1/03 19:00	-1.5 MSL	7.57	45	1.6	5	45

It should be noted that, wind speeds in table have been adjusted from wind measurement at 70m above sea level to the wind speed at 10m heights for the requirement of the model parameter as mentioned in *chapter 2*. It also have to mention that wave directions in offshore boundary are taken as the same measured wind direction in offshore.

SWAN has two options to put these boundaries into model; they are either constant boundary condition (CON) or variable boundary condition (VAR). In the former option the incoming wave components in the simulations are assumed to be uniform along the up-wave boundary while they are assumed to be variable along the up-wave boundary in the later option. The effect of different ways on the result of the model will be investigated in *chapter 5*.

4.3.2 Boundary conditions for model calibration

In *chapter 5* model calibration will be carried out, it is thus necessary to set up the boundary conditions employed for that task. Considering all available source of data and the available time for modelling activities, it was decided to select only one tidal cycle within each short term data to perform computations. To this end, based on the data coverage at measurement station and intensity of wave condition, in summer monsoon the period from 6/8/2002 4:00 to 7/8/2002 4:00 was selected to perform computation, in winter time the period from 4/1/2003 19:00 to 5/1/2003 19:00 is selected.

Wave conditions at the offshore boundary were taken from the measurements at Bach Long Vi station. At the same time available measured wave data nearshore in Van Ly were used to refer for the littoral wave condition to evaluate the performance of SWAN. *Table 4-7* summaries the wave parameters applied at the offshore boundary for two selected periods. Also the wind speed, wind direction as well as the water level for each time step are listed in *table 4-7*.

Table 4-7. Boundary condition for model calibration

Set No	Time step	Water level (MSL)	Wind condition		Offshore wave condition		
			U_{10} (m/s)	Dir(Nau. deg)	H_s (m)	T_p (s)	Dir(Nau. deg)
1	06-08-02 4:00	-1.0	3.78	203	0,4	3	203
	06-08-02 7:00	-0.3	5.3	203.	0.9	4.	203.
	06-08-02 10:00	0.6	7.57	203.	1.8	6.	203.
	06-08-02 13:00	1.2	5.3	225.	0.9	4.	225.
	06-08-02 16:00	1.0	5.3	203.	0.9	4.	203.
	06-08-02 19:00	0.5	7.57	203.	1.8	6.	203.
	06-08-02 22:00	-0.2	5.3	203.	0.9	4.	203.
	07-08-02 1:00	-0.9	3.78	180	0,4	3	180
	07-08-02 4:00	-1.0	3.78	180	0,4	3	180

Set No	Time step	Water level (MSL)	Wind condition		Offshore wave condition		
			U_{10} (m/s)	Dir(Nau. deg)	H_s (m)	T_p (s)	Dir(Nau. deg)
2	04-01-03 19:00	-1.5	7.57	45.	1.6	5.	45.
	04-01-03 22:00	-0.4	9.84	45.	2.4	6.	45.
	05-01-03 1:00	1.0	7.57	45.	1.6	5.	45.
	05-01-03 4:00	1.5	7.57	45.	1.6	5.	45.
	05-01-03 7:00	1.4	9.84	45.	2.4	6.	45.
	05-01-03 10:00	0.6	9.84	45.	2.4	6.	45.
	05-01-03 13:00	-0.3	9.84	45.	2.4	6.	45.
	05-01-03 16:00	-1.1	9.84	45.	2.4	6.	45.
	05-01-03 19:00	-1.3	11.4	45.	2.9	7.	45.

4.3.2 Boundary conditions for model application

Available data at Bach Long Vi island in 20 years has been analysed and resulted in the data set of yearly average wave climate at that measurement station as mentioned in *chapter 2*. This data will be employed for the model computation in *chapter 6*. More specific description of above mentioned condition at offshore boundary is treated below.

4.3.2.1 Wind

Since the open boundary for computational grid is only in one side, out of 16 directions of wind measurement data as mentioned in *chapter 2*, only 9 directions will be taken into account for nearshore wave computations. The wind conditions for those directions are given in *table 4-8*. For fully wind data set, readers are referred to *chapter 2*.

Table 4-8. Description of wind conditions for model application

Mean wind direction (^{o})	45	67.5	90	112.5	135	157.5	180	202.5	225
Averaged wind speed U_{10} (m/s)	5.85	3.94	3.28	3.37	3.24	5.21	5.95	5.04	3.87

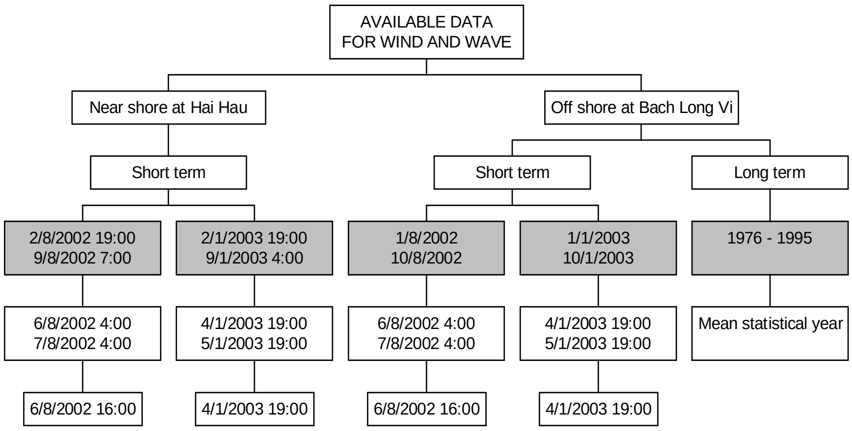
4.3.2.2 Wave

The wave hindcasted from wind can be taken as the offshore wave boundary conditions for the model. *Table 4-9* describes the input parameters related to wave condition for model simulations.

4.3.2.3 Water level

The water level used in this assignment is obtained from tide table and bathymetry chart as mentioned in *chapter 2*. The mean water level (MWL) will be used in this assignment for mean statistical year to see how influence of it on the nearshore wave climate and on the sediment transport along the shore.

❖ *Summary of available data and data adopted for the present study is displayed in figure 4-3.*



Note: Grey colour boxes represent the available data;
White colour boxes represent the data adopted for the present study;

Figure 4-3. Available data and data adopted for the study

4.4 WORK PLAN

Computations related to this study were carried out according to a work plan. Basically three main streams of computations were established. They are the computations for sensitivity analysis, for model calibration and computations for data set of mean statistical year. *Figure 4-4* describes the adopted work plan for this particular assignment.

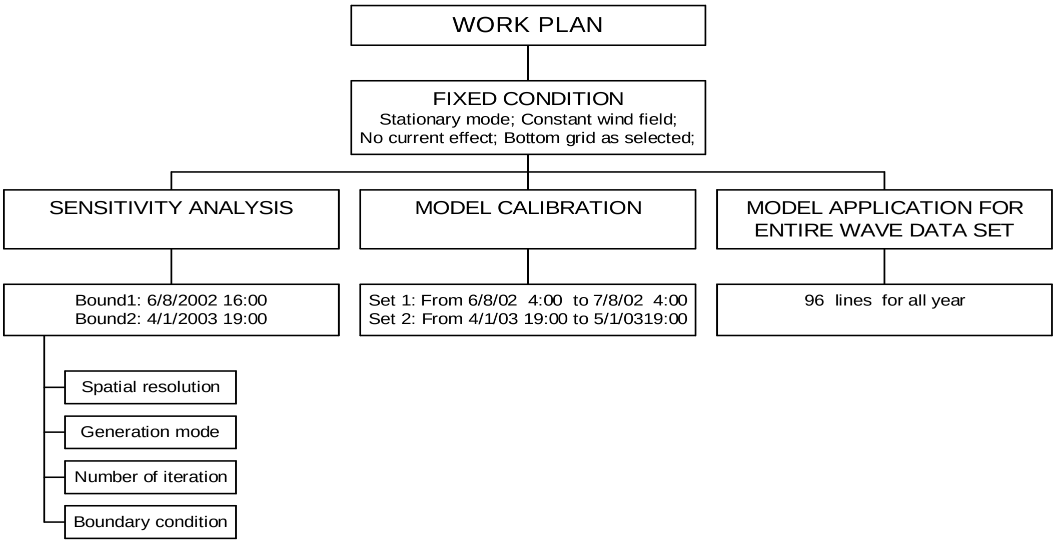


Figure 4-4. Work plan for model computations

Typical SWAN command file for the above grid set-ups are included in *Appendix 4-1*. For each model run, the results were extracted for significant wave height H_s, peak wave period T_p and mean wave direction θ in the entire computational area and along several depth contours. Also, wave parameters at pre-specified locations were requested to check against the available measurements. These results will be analysed in various form to investigate the sensitivity of model, calibrate the model and to evaluate the performance of model with respect to sediment transport. Details are included in the chapters to be followed.

4.5 CONCLUSIONS

In brief, model settings and schematisations have been carried out in this section. Summary of alternatives and assumptions adopted for the study are given below:

- *In the case presented in this thesis, analysis has demonstrated that a rectangular grid extending till Bach Long Vi island in the east, till the land in the north, south ward and rotate 45^o relative to the north seems to suggest the most reasonable grid and thus has been selected for model simulations.*

- *The SWAN in stationary mode was employed in this study. This is considered acceptable for most coastal applications since the residence time of the waves in the computational area is expected to be far less than the time scale of variations of the wave boundary condition, the wind and the tide.*

- *The situation presented in this study was characterised with the absence of currents since no ready sufficient available data exists and also due to the fact that recorded data proved that current velocity in this area is not too high and can be neglected.*

- *The wind condition is assumed to be uniform over the entire computational grid. This assumption, in fact, may result in inaccurate output. However, at present, due to lack of data, there has not been enough opportunity to set up variable wind condition on the computational grid. Therefore, such simplified assumption has been adopted for model simulations.*

Chapter 5

SENSITIVITY ANALYSIS AND MODEL CALIBRATION

5.1 BACKGROUND

In general, as part of the task to calibrate the model, a sensitivity analysis has to be carried out. The results from that investigation will be helpful to suggest a set of parameters for model calibration.

In this chapter, firstly the sensitivity of SWAN with respect to a number of parameters will be carried out. They shall include investigations an effect of spatial resolution, physical phenomena (generation mode), wave boundary conditions and wind field conditions. This includes also the convergence problem in SWAN encountered when applying an ultimate choice for all physical processes. Subsequently, a model calibration will be carried out based on the results derived from model sensitivity analysis. Finally, a set of parameters along with necessary remarks will be suggested for model application in *chapter 6*.

5.2 SENSITIVITY ANALYSIS

This section deals with the computed results that are in the form of block outputs, the ray along the contour line outputs and output at a pre-specified location. Graphical representation of the extent and position of those required outputs are displayed in *figure 5-1*. Although the results are available for a variety of variables related to waves, for the purpose of this chapter, only three variables will be called for, they shall include significant wave height (H_s) and peak wave period (T_p) and mean wave direction (θ).

Two boundary conditions used for sensitivity analysis as mentioned in *chapter 4* are briefed in *table 5-1*.

Table 5-1. Two boundary conditions for sensitivity analyses

Boundary N°	Water level	Wind condition		Offshore wave condition		
		U_{10} (m/s)	*Dir (Nau.deg)*	H_s (m)	T_p (s)	*Dir (Nau.deg)*
1	1.0 MSL	5.3	203	0.9	4	203
2	-1.5 MSL	7.57	45	1.6	5	45

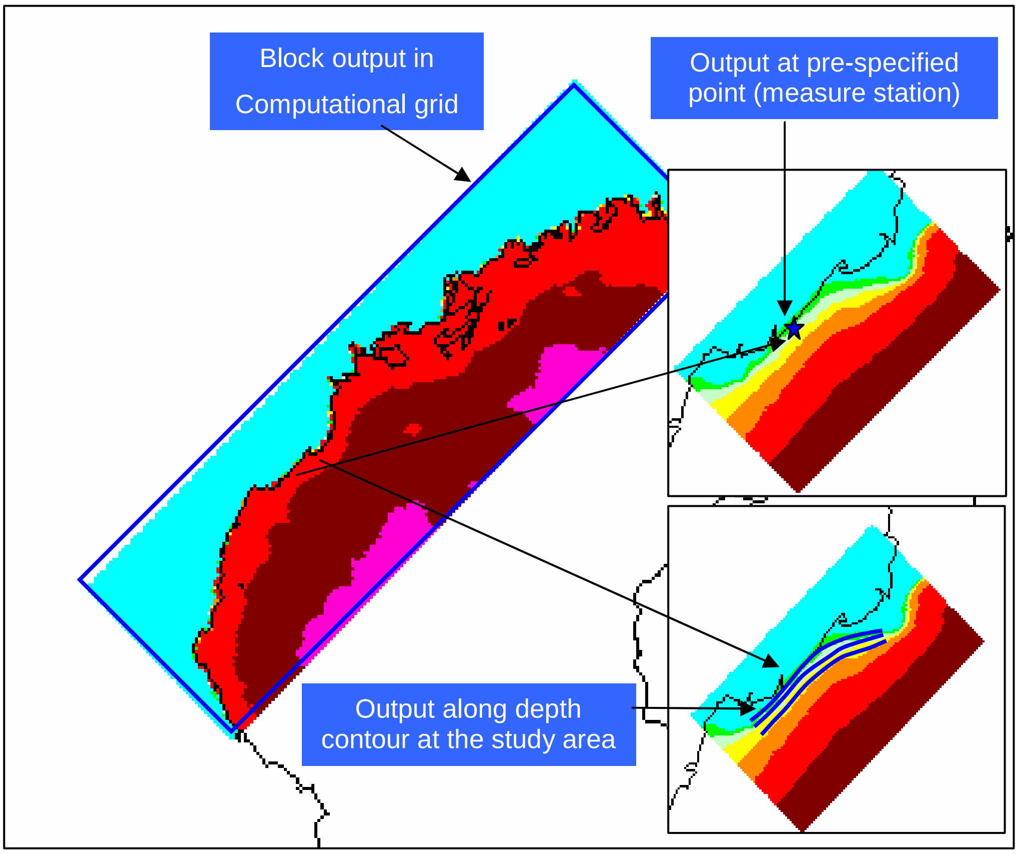


Figure 5-1. Graphical representation for 3 types of required output

Detailed analysis of the behaviour of model against the variation of some parameters would be presented in the following sub-sections.

5.2.1 Spatial resolution

In this sub-section, the sensitivity of SWAN is checked with respect to the spatial resolution of the computational grid. The problem is relevant because usually a higher resolution gives more accurate results, but it also increases the computer time. The ultimate choice is necessarily a trade-off between these two requirements.

In this particular case, it should be noted that, as descried in *4-2-2* the bottom grid applied for the study is 1000x1000m and it was also stressed that it is best to select the computational grid identical with input grid. Thus, it can be deduced that the best option for computational grid in this study should be 1000x1000m. However, as this option will require long time for computation, so it is necessary to explore the behaviour of model between different alternatives for grid size of computational grid to select an optimal option. For that reason, the wave computations with resolutions of 3000m, 2000m, 1000m and 500m were carried out with equal other numerical settings. Basically the model results produced by the GEN3 mode (activating all physical processes), constant boundary condition and standard accuracy criterion will be utilised for this analysis. It should be noted that in case of 500m spatial resolutions, the option of nesting grid is selected by using a fine grid (500m) of limited extent, covering the interested area embedded in a more extended and coarser grid (2000m). Illustrations of all spatial computational grids are displayed in *figure 5-2*. An overview of model simulations and behaviour of the model in term of time required are presented in *table 5-2*.

Table 5-2. Overview of wave simulations and time required for the sensitivity analysis of SWAN against spatial resolutions

Case	Boundary N°	Grid size (mxm)	Time for model run
1	1	3000x3000	25min
2	1	2000x2000	50min
3	1	1000x1000	3h20min
4	1	2000x2000	100min
	Nesting	500x500	
5	2	3000x3000	25min
6	2	2000x2000	50min
7	2	1000x1000	3h20min
8	2	2000x2000	100min
	Nesting	500x500	

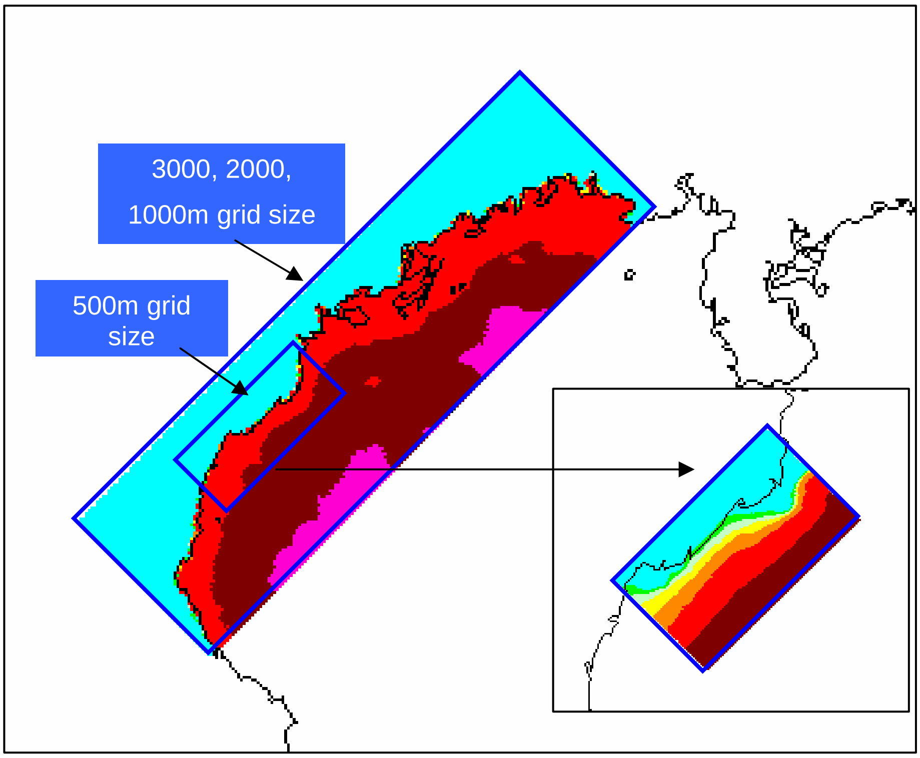


Figure 5-2. Illustration of spatial computational grids

Regarding the comparison between two cases of 3000m and 1000m resolution, the difference and relative difference in predicted wave heights H_s and peak wave periods T_p are shown in *App.5-1, 5-2* for boundary 1 and *App. 5-3, 5-4* for two boundary 2.

Looking at each upper panel in *App.5-1* and *App.5-3*, it can be seen that the difference in predicted wave height can be up to 40cm in some water areas. The corresponding relative difference is more than 40% (see *App.5-2 and App.5-4)*. In this situation, the wave height is locally sensitive with respect to the spatial resolution. For the peak wave period, the difference can be up to 2,5s and the corresponding relative difference is more than 40% but only in some areas besides the land boundaries.

Similarly, *App. from 5-5 to 5-8* show the comparisons between predicted wave heights and peak wave periods for two alternatives of grid size 2000m and 1000m of two boundaries. It is also found that the two spatial resolutions generally predict the wave parameters with very small difference in the deep-water area but noticeable difference in the shallow water area.

It could be understood that the bathymetry is complicated, resulting in the considerable varying wave field in the area besides the land. In general, we can conclude that the difference in spatial resolution may cause significant change in the result, but such changes only occur at the complex boundaries of the area.

To investigate the influence of spatial resolution on the wave predictions at the interested area in Hai Hau coast, an analysis for the outcome along some depth contours has been implemented. *App. 5-9 and 5-10* show comparisons between the computed significant wave heights H_s and peak wave periods T_p at some positions along the depth contour of 2, 3 and 8m for different spatial resolutions. Since the case of 500m grid size is the nesting grid, the comparison could not be made in form of block output like other cases. Only the results at a number of specified points along depth contour are to be compared with other alternatives. Those comparisons are also included in *App.5-9, 5-10*.

From A*pp.5-9 and 5-10*, it is found that the tendencies in the results with three resolutions of 2000, 1000 and 500m are fairly similar, especially two grid size 1000 and 500m, but the spatial resolution of 3000m tends to give higher significant wave height and peak wave period than other grids. Such difference could be understood through the Courant number for accuracy criterion of model run. Even SWAN is based on implicit numerical schemes, meaning that it is always unconditionally stable, but the accuracy of results of SWAN are obviously affected by the space step. It is clear that higher spatial resolution of 3000m will result in some loss of accuracy in model run compared with smaller spatial resolutions. Also, outputs required along depth contour are to be extracted from computational grid by interpolation procedure. Therefore, in the area near the land in the presence of complex topography, such interpolation procedure will certainly result in different outcome if the grid sizes are different from each other.

If considering the computational time for different SWAN runs, it can be seen from *table 5-2* that the computational time in case of 3000m resolution is 25 minutes, for 2000m case is 50 minutes. The option of 500m with nesting technique requires 100 minutes for one scenario, whereas time required for option of 1000m is the most with 3 hours 20 minutes and much longer than other options. (The above-mentioned times are for high capacity computer)

As mentioned earlier, the option of 1000m-grid size for computational grid is considered as the best since it takes equal resolution with the selected input grid, so no error due to interpolation procedure will occur. However, as a result, the computer time required for it is longer. It is thus better to select the grid size that predicts the outcome ***at the study area*** more or less the same with the option of 1000m but time required is less. For that reason, it can be proposed that two possible alternatives to predict the wave conditions accurately and economically in this particular case is the resolution of 2000m and 500m with nesting technique. The final choice would be made after considering the comparison with measured data, which would be done at the end of this section. For the purpose of completeness, in the next coming sub-sections, the resolution of 2000m will be adopted.

5.2.2 Physical processes (Generation mode)

This sub-section investigates the influence of deep-water wave physical process such as quadruplet wave interaction on the model performance. Actually, the presence of this process in a model run is expressed in the choice between third generation mode (GEN3) and second-generation mode (GEN2). For more details of difference between these two modes, reference is made to *chapter 3*. Here after, the term of GEN2 and GEN3 will be used implying for deactivating and activating the quadruplet process, respectively.

Use of the wave prediction models in the third generation (GEN3) is always the best from a point of view of quality, but the price is that an enormous computation effort and much more time is to be expected. In addition, some time it is hard to converge for the final solution with standard convergence criterion with this option. Because of that, for each particular situation, possible solution is to consider the GEN2 but then it would be verified characteristic computation with the GEN3 mode. In this way, the users can see how good the GEN2 works in their cases.

Concerning the sensitivity analysis of SWAN with respect to the generation mode, 4 cases using two boundary conditions have been carried out in this assignment. Overview of model simulations, behaviour of model in term of time required and accuracy obtained are given in *table 5-3*. Comparison results of significant wave heights and peak wave periods in graphical form are displayed in *App.5-11 to 5-16.*

Table 5-3. Overview of wave simulations and behaviour of model for the sensitivity analysis of SWAN against generation mode

Case N^o	Boundary N^o	GEN	N^o of iteration	Acc (%)	Time
1	1	GEN3	15	87.6	50min
2	1	GEN2	8	98.2	25min
3	2	GEN3	15	98.2	50min
4	2	GEN2	10	99.3	25min
5	1	GEN3	50 iteration	78.5	2h40min

In the following, the sensitivity of SWAN with respect to generation mode will be investigated.

According to *App. from 5-11 to 5-14*, it can be found that the difference of wave predictions between GEN2 and GEN3 is remarkable. The absolute difference in predicted wave heights between GEN 2 and GEN3 can be up to 50cm (see the upper panel of *App.5-11 and 5-13*) and the absolute difference of predicted peak wave period can be up to 3s (see lower panel of *App. 5-11 and 5-13*). The corresponding relative difference for both significant wave height and peak wave period can be up to 50%.

It is easier to see the difference between two options in *App. 5-15 and 5-16* for the comparison of computed wave heights and peak wave periods along depth contour of 2, 3 and 8m of two boundary conditions. From these figures, we can observe that the computed wave heights in case of GEN3 mode is higher than that in case of GEN2 mode. It can be explained that in GEN3 mode the process of quadruplet wave-wave interaction is explicitly considered. Functionality of this process is to redistribute energy over spectrum (As mentioned in chapter 3), energy from short wave components is transferred to long wave components. These newly generated components seem to be longer, so they are more stable and the presence of white-capping process is less, as a result integrated energy spectrum in case of GEN3 mode is higher than in case of GEN2 mode, where the process of quadruplet wave interaction is only considered implicitly. Also, the presence of quadruplet will move peak frequency to lower value resulting in higher value of peak period as can be seen in *App.5-15 and 5-16.*

Results from *table 5-3* show that in case of GEN3 mode with standard accuracy criterion the model run hasn't converged to the final solution in case of boundary 1, while in GEN2 case the model run has been terminated before pre-specified number of iteration. This implies that the convergence problem may occur in case of GEN3 mode.

As explained earlier, the alternative of GEN3 mode is always the best in terms of quality even it may consume more time. In this particular case since the model may not converge to final solution, this initiate the idea to investigate the degree of influence of GEN3 mode in convergence problem. One more wave computation was carried with the same parameter set up as in case 1 (table 5-3) except the number of iteration of 50. This is named case 5 in table 5-3. Also, time required and accuracy achieved after model run is given in this table.

From the obtained accuracy and time required, we can find that even after 50 iterations, the wave prediction haven't yet converged to the final solutions (98%). The reason is as explained earlier that in GEN3 mode, the process of quadruplet interaction is considered explicitly. As mentioned in SWAN impletation manual, a full computation of this process is extremly time consuming. It may be still a limitation of model.

It is proved through model runs that the degree of convergence expressed by value of accuracy achieved after each iteration step is arbitrary, it cannot be guessed by feeling. It is not true to say the more number of iteration model run the more accuracy we will get. The explanation for that comment is related to mathematical formulation in the model. It is beyond the scope of this study, therefore will not be mentioned here. Only, for further computations, if the option of third generation is selected, this drawback should be taken into consideration to optimise the results from model.

It can be concluded that in case of the GEN3 mode, the convergence problem may occur; the magnitude of influence depends on each specific scenario. In case of GEN2 mode, the disadvantage in GEN3 is overcome, the model is easier to converge to final solution. However, considerable differences are observed in the predicted significant wave height and peak wave period between GEN2 mode compared with GEN3 mode. Thus, the ultimate choice for generation mode and the corresponding solution will be made after verifying with measured data.

5.2.3 Boundary conditions

In order to make a good comparison between two options of constant and varying boundary condition, the variation of wave height along the open boundary in the latter option is adopted in such a way that it starts from the magnitude of 0m approximately at land and then linearly changes according to the variation of bathymetry and at Bach Long Vi island the magnitude is equal to the available data. In this way, the difference of wave simulation results between the case of simplified assumption in option 1 and the case of more realistic condition in option 2 can clearly be observed.

Four model runs were performed in this regard for two cases of boundary conditions with two options of constant and varying wave condition at boundary. The absolute and relative different of predicted wave heights and wave periods within the computational grid between two options are shown in *App.5-17 to 5-20.* Two other plots were made in *App. 5-21 and 5-22* to perform the model results extracted for significant wave heights and peak wave periods in some points along depth contour.

From the *App.5-17 and App.5-19*, it can be seen that the maximum difference in prediction of H_s and T_p are 0.8m and 3s respectively for boundary condition 1 (see *App.5-17*) and are 1.5m and 4s respectively for boundary condition 2 (see *App.5-19*). These remarkable differences are observed in the North and South of the computational grid. This is simply due to different pattern of wave condition at boundary.

Concerning the difference between two cases at the interested area, outputs of H_s and T_p were requested at a number of locations along depth contour of 2, 3 and 8m. The comparisons are shown in *App.5-21* and *App. 5-22*. The observed differences in significant wave heights and peak wave periods, say, are found to be of the order 2cm and at most 1s for both sets of boundary.

It is evident that different boundary conditions will result in different output, but such effect is not so much in the extent of project site far from boundary. It is clearly that varying wave condition is closer to the real situation than the case of constant wave condition. But for the time being, the actual variation of wave condition is unknown, so the final option for future computations will be made after comparing model output with measured data.

5.2.4 Evaluation of model results

In order to make qualitative assessment of the model predictions, the predicted wave parameters at pre-specified location namely LT3 in Van ly of all model runs up to now are called for to compare with measurements. *Table 5-4 show* comparisons between measured and computed wave parameters at the observation location.

Table 5-4. Comparison between model results and measurement at near shore in Van Ly

	Computation	Case	Grid size	Generation	Type of bound	Hs(m)	Tp(s)	Dir(Deg)
Bou1		1	3000x3000	GEN3	Constant	0.83	4.7	200
		2	2000x2000	GEN3	Constant	0.7	3.5	195
		3	1000x1000	GEN3	Constant	0.73	3.8	196
	➔	4	**500x500**	**GEN3**	Constant	**0.75**	**4.2**	**198**
		5	2000x2000	GEN2	Constant	0.54	2.9	200
		6	2000x2000	GEN3	Varying	0.62	3.9	196
	Measurement					**0.78**	**9.14**	**142**
	Computation	Case	Grid size	Generation	Boundary	Hs(m)	Tp(s)	Dir(Deg)
Bou2		1	3000x3000	GEN3	Constant	0.55	5.2	86
		2	2000x2000	GEN3	Constant	0.48	5.2	89
		3	1000x1000	GEN3	Constant	0.51	4.7	84
	➔	4	**500x500**	**GEN3**	Constant	**0.52**	**4.7**	**84**
		5	2000x2000	GEN2	Constant	0.38	4.7	77
		6	2000x2000	GEN3	Varying	0.45	4.2	84
	Measurement					**0.51**	**4.92**	**76**

According to *table 5-4*, it can be found that for boundary 1, the SWAN model appears to underestimate the value of peak frequency and also, the mean wave directions at the near shore predicted by the model don't agree with the observed direction. For boundary 2, the model seems to predict wave parameters better, all output are closer to the measured data compared with the case of boundary 1. Looking at the difference in results of all wave parameters for 12 cases of two boundaries, the best agreement (at least for significant wave height) in two test cases is obtained with the spatial resolutions of 1000m and 500m spatial resolution, GEN3 and constant boundary condition. However, as mentioned earlier in term of time required, 1000m grid size will take twice longer than 500m grid size. Therefore, the parameter set of 500m grid size, GEN3 mode, and constant boundary condition seem to suggest the most appealing option in both accuracy and economy aspect. In this particular case, it is thus to be proposed for further computations to calibrate the model.

It should be noted that, as discussed earlier, the choice of third generation (GEN3) mode might face with the problem of convergence. A practice procedure is to relax the accuracy criterion so that the model can converge to final solution. In details, instead of standard accuracy criterion *Drel= 2%, dHasb=2cm, dTabs=2s, Npnts=98%,* it shall be *Drel= 3%, dHasb=3cm, dTabs=3s, Npnts=97%*. In this way, model run is expected to be easier to converge with slightly loss of accuracy. The selected parameters accompany with above remark will be employed for model calibration to be presented in next coming section.

5.2.5 Conclusions

In brief, the sensitivity of SWAN has been investigated in this section. The following conclusions were obtained:

- *In general, the model tends to produce inaccurate results in the presence of complicated bottom topographies and land boundary with coarse grid size. The wave predictions are locally sensitive to the spatial resolution. If required, the nesting technique should be used to predict the wave computation accurately and economically at the area of interest.*
- *In Nam Dinh coast, the spatial resolution of 500m with nesting technique generally is fine enough to predict wave condition. With this option the model results are more or less the same with measured data and time required for it is reasonable.*
- *The choice of GEN3 mode is considered as the best in terms of quality, but with this option the convergence problem may occur; the magnitude of influence depends on each specific scenario. In case of GEN2 mode, the disadvantage in GEN3 is overcome but considerable difference is observed in the predicted significant wave height and peak wave period compared with GEN3 mode. The trend of these differences is that predicted significant wave height and peak wave period in GEN3 mode is higher than that in case of GEN2 mode. The explanation was found due to the effect of quadruplet wave interaction process in GEN3 mode.*
- *In the case of Nam Dinh coast, the comparison with measured data showed that result from GEN3 mode is closer with the measured data than GEN2 mode. It is thus suggested to use for model calibration.*
- *Wave boundary condition patterns have influence on the results of wave simulation. The option of varying wave condition seems to be closer to the real situation than option of constant boundary. But, in turn, it requires more data and effort to achieve a proper condition at the boundary. Which boundary condition should be used? The final decision should be made based on the comparison with available measured data. In this particular case, the option of constant boundary condition is employed for model calibration.*

5.3 MODEL CALIBRATION

5.3.1 General

The model was calibrated based on available data of measurement in period from 2 to 9/8/2002 and from 2 to 9/1/2003. From the extensive data set, two time interval representing for two tidal circles in summer and winter monsoon are selected for calibrating the model. The description of the selected time period for model calibration was already given in *chapter 4.* For the aim of completeness, a brief description is given in *table 5-5* including the measured near shore wave data, the available off shore wind and wave condition as well as the water level.

Table 5-5. The data used for model calibration

Set No	Case	Water level (MSL)	Wind condition		Offshore wave climate			Measured near shore wave climate		
			U_{10} (m/s)	Dir(Nau .deg)	H_s (m)	T_p (s)	Dir(Nau .deg)	H_s (m)	T_p (s)	Dir(Nau .deg)
1	1	-1.0	3.78	203	0,4	3.	203	0.36	7.11	143
	2	-0.3	5.3	203.	0.9	4.	203.	0.36	4.92	143
	3	0.6	7.57	203.	1.8	6.	203.	0.39	4.92	143
	4	1.2	5.3	225.	0.9	4.	225.	0.52	9.14	143
	5	1.0	5.3	203.	0.9	4.	203.	0.78	9.14	142
	6	0.5	7.57	203.	1.8	6.	203.	0.91	7.11	142
	7	-0.2	5.3	203.	0.9	4.	203.	0.61	9.14	142
	8	-0.9	3.78	180	0,4	3.	180	0.52	7.11	142
	9	-1.0	3.78	180	0,4	3.	180	0.38	9.14	146
2	10	-1.5	7.57	45.	1.6	5.	45.	0.51	4.92	76
	11	-0.4	9.84	45.	2.4	6.	45.	0.66	4.92	76
	12	1.0	7.57	45.	1.6	5.	45.	0.77	4.92	76
	13	1.5	7.57	45.	1.6	5.	45.	0.92	5.82	76
	14	1.4	9.84	45.	2.4	6.	45.	1.1	7.11	76
	15	0.6	9.84	45.	2.4	6.	45.	1.08	5.82	136
	16	-0.3	9.84	45.	2.4	6.	45.	0.95	7.11	137
	17	-1.1	9.84	45.	2.4	6.	45.	0.66	5.82	137
	18	-1.3	11.4	45.	2.9	7.	45.	0.69	7.11	137

It should be mentioned that, from the comparison in *table 5-4*, we realised that even the selected parameter set result in the excellent agreement between computed significant wave heights and measured data, but it still could not reproduce well the value of peak wave period and mean wave direction. The possible reason could be that by assuming uniform wind coming from the same direction as mean wave direction in the entire computational grid, this causes the wave condition in near shore to be affected by wind conditions as the same as in offshore. It was acknowledged that such assumption, in fact, does not correspond with the real situation since the wind field may vary spatially due to different roughness conditions on land and sea, and also for different sea states. So the wind velocity and wind direction at the near shore can be different from the off shore resulting in changing the direction of mean wave at the near shore. Unfortunately, due to lack of data, that error has still not been addressed in this study. Any way, as part of a more comprehensive evaluation of model performance and to have more choices within the task of model calibration, further investigation will be carried out to determine the sensitivity of model with respect to wind condition. This task will be done on the basis of selected parameter as mentioned in previous section by adjusting wind direction until mean wave direction at nearshore is almost consistent with measured data.

5.3.2 Model results

A series of wave computations have been carried out to evaluate the performance of SWAN model in this particular case using selected parameters. The approach is that initially the model will be run in case the wind direction is assumed the same as the mean wave direction and subsequently the model will be run in such a way that the uniform wind direction in the computational grid is adjusted so that the mean wave direction at near shore almost consistent with the measured data.

The computed values of significant wave height H_s, peak wave period T_p and mean wave direction θ for two approaches are presented in *table 5-6*. Graphical representations for comparison between outputs from two methods with measured data are displayed in *figure 5-3*. Typical output file and computed pattern of significant wave height and mean wave direction is given in *App.5-23.*

Table 5-6. Comparison between modelling results and measurement at Van Ly from 6/8/02 4:00 to 7/8/02 4:00 and from 4/1/03 19:00 to 5/1/03 19:00

Measured data			Model results in case the same wind,wave direction at boundary			Model results in case different wind,wave direction at boundary		
Hs (m)	Tp (s)	θ (Nau,Deg)	Hs (m)	Tp (s)	θ (Nau,Deg)	Hs (m)	Tp (s)	θ (Nau,Deg)
0.36	7.11	143	0.33	2.9	197	0.3	2.9	142
0.36	4.92	143	0.59	3.9	192	0.5	3.5	145
0.39	4.92	143	0.8	4.7	180	0.78	4.2	148
0.52	9.14	143	0.53	3.9	198	0.42	3.5	150
0.78	9.14	142	0.75	4.7	198	0.68	4.7	148
0.91	7.11	142	0.86	4.7	181	0.8	4.2	147
0.61	9.14	142	0.62	3.9	196	0.55	3.5	143
0.52	7.11	142	0.34	2.9	191	0.3	2.9	143
0.38	9.14	146	0.35	2.4	192	0.3	2.4	145
0.51	4.92	76	0.52	4.7	84	0.45	5.2	76
0.66	4.92	76	0.89	6.3	89	0.8	6.3	78
0.77	4.92	76	0.78	4.7	74	0.68	4.3	75
0.92	5.82	76	0.92	4.7	73	0.8	4.3	76
1.1	7.11	76	1.12	6.3	81	0.98	6.3	74
1.08	5.82	136	1.03	6.3	84	1.14	5.2	137
0.95	7.11	137	0.89	6.3	88	1.03	5.2	136
0.66	5.82	137	0.78	6.3	92	0.85	5.2	137
0.69	7.11	137	0.91	6.3	97	1.02	5.2	137

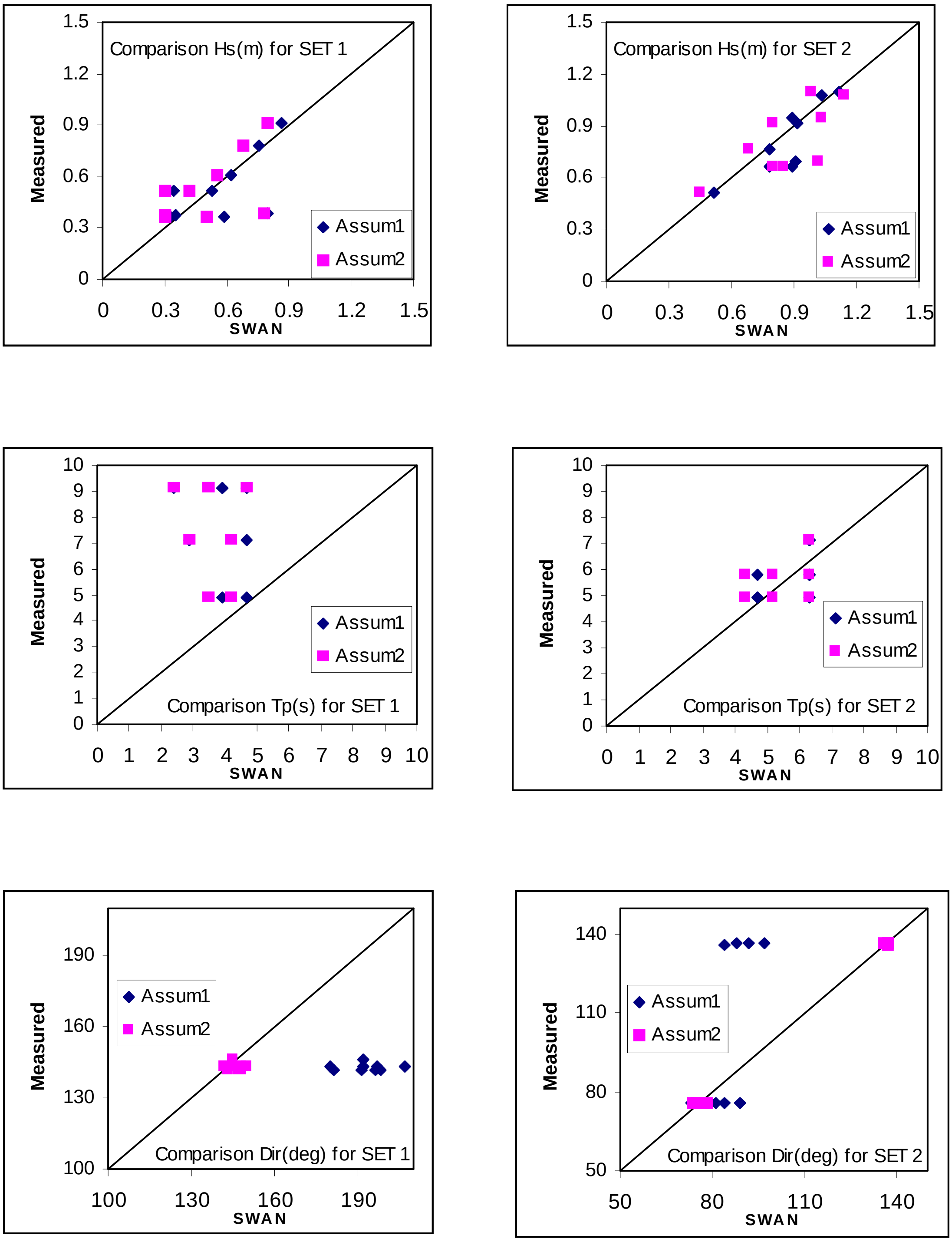


Figure 5-3. Comparison between computed and measured Hs, Tp and wave direction

5.3.3 Discussions

➢ ***Discussion on the results of the case when putting the same wind, wave direction at boundary***

Firstly, considering the case when maintaining the direction of wind the same as wave direction at offshore, it can be proved from *table 5-6* and *figure 5-3* that the agreements between computed results and the observation is generally reasonable for the significant wave heights H_s but very poor for the value of peak wave period T_p and mean wave direction θ especially with set boundary 1.

Looking at the value of peak wave period, there is a significant difference between the measured data and computed results in case of set 1 (see the grey colour in *table 5-6*), while this differences seem to be lesser in case of set 2. In set boundary 1, although peak wave period from the measurement is about 5-9s, the model results only manage to predict a maximum of 4.7s. It is not the case of set boundary 2, where the peak wave measurement is about 5-7s, the model can predict more or less the same value. Then, what is the reason causing such differences? In order to find the reasonable explanation, let's consider the wave boundary condition offshore.

Offshore wave climates as given in *table 5-5* show that, with regards to peak wave period in set boundary 1, most of them are in the order of 3 and 4 s (implying for short crested waves), except two cases of 6s waves. In set boundary 2, peak wave periods appear to be higher with the value from 5 to 7s. Relating these notices with the earlier mentioned comments, it is demonstrated that significant difference between measured data and computed results only occur in case that wave conditions offshore are short waves with small period (See the value in grey colour in *table 5-6*). For instance, in case 1, T_p at offshore is 3s, T_p at near shore as measured is 7.11s, while T_p at near shore as computed is only 2.9s, so absolute difference is more than 4s. Similarly, in case 8, T_p at offshore is 4s, T_p at near shore as measured is 9.14s, while T_p at nearshore as computed is only 3.9s, so absolute difference is more than 5s. It is not the cases for T_p at offshore is more than 5s.

In general, the correlation between peak wave period measured offshore and nearshore computed seems logical. On the other hand, this relation does not seem to be reliable as measured. This thus initiates the idea of finding the possible error in wave measure instrument.

As mentioned in chapter 2, a pressure transducer named VALEPORT-730D, positioned in water, 60cm above seabed, measured nearshore wave data. The principle of operation of this instrument is that it can measure wave-induced pressure fluctuations, then the pressure fluctuations can be used to reconstruct the motion of the sea surface itself to define some wave parameters such as wave height, wave period, and mean wave direction. What is the wave-induced pressure? For the purpose to clarify the possible drawback of the measure instrument, brief description of theory about pressure is presented below. (Referred from section 4-6, lecture note ‘Short wave’ – IHE)

Total subsurface pressure can be written as the sum of hydrostatic contribution and the linear wave-induced pressure (also called dynamic pressure)

$$p(x,z,t) = p_{hydrostastic}(z) + p'(x,z,t) \qquad (5\text{-}1)$$

The first term in the right hand size of equation (5-1) is the hydrostatic term, which would exist without the presence of the wave, while the second term is the dynamic component due to the presence of wave. For the purpose of determining the wave parameters, only the dynamic pressure term is interested. Detailed expression of the second term in equation (5-1) is given below:

$$p'(x,z,t) = \rho g a \frac{\cosh(k(h+z))}{\cosh(kh)} \cos(kx - \omega t) \qquad (5\text{-}2)$$

In deep water condition equation (5-2) can be approximated by:

$$p'(x,z,t) = \rho g a \times e^{kz} \times \cos(kx - \omega t) \qquad (5\text{-}3)$$

Therefore, in deep water condition with increasing depths the dynamic pressure decreases, and till at z=-Lo/2, the pressure is unaffected by the wave action. The pressure simply equals the hydrostatic pressure.

The above mentioned theory is relevant for explanation of error in measured data since according to that theory, if the instrument is placed too deep in the water it cannot measure the short wave component, but only the long wave component. This can be seen more clearly in *figure 5-4*.

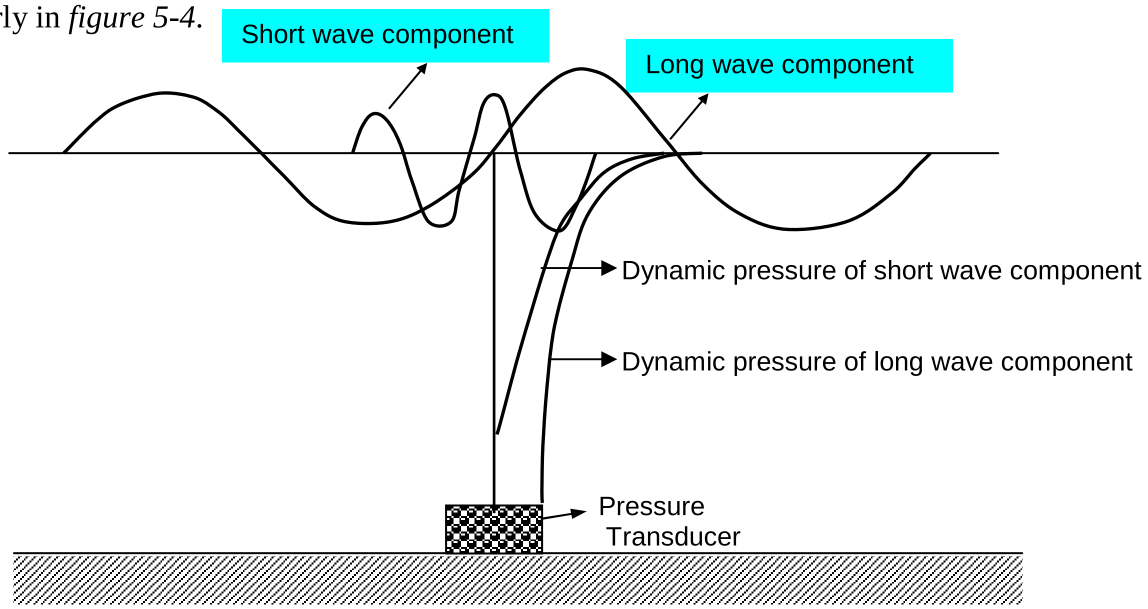


Figure 5-4. Dynamic pressure component in deep water (short wave) and intermediate deep water (Long wave)

Assuming that the explanation as above is true for the measurement work in the field site, it means that if the coming wave is too short the measure device cannot register it. Then, what is the result of high value of peak period as measured while offshore wave climate is low peak period. To account for this, another hypothesis has been found.

As mentioned in *chapter 2*, in the Gulf of Tokin, short wind waves are predominant. The real situation in the project site proved that swell still could approach the shore from SE direction. This wave component is defined as long crested wave and with a longer period than the wind wave, so these wave components, if occurring, will be recorded by the measure device, resulting in the high value of peak period. Description of above situation in form of wave energy spectrum is illustrated in *figure 5-5*.

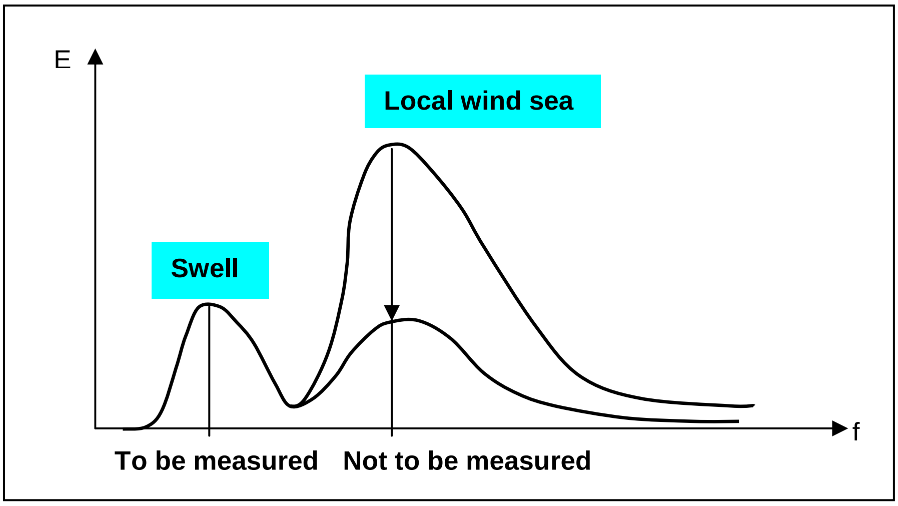


Figure 5-5. Wave energy spectrum in case sea and swell occur simultaneously

It can be concluded that even the agreement between computed and measured peak wave period is not well, the possible reason found is due to the error in measure device. The results from the model seem to make more sense. Therefore, future calculations can still accept the parameter set up with reliability of the results in term of peak wave period.

With respect to mean wave direction, as can be seen from *table 5-6,* model could not reproduce the value of mean wave direction as measured. In general, the model tends to shift the mean wave directions more to South ward compared with measured data. This supports the fact that, by putting uniform wind condition having the same direction with mean wave direction at boundary, model cannot predict mean wave direction at near shore properly. Then, how the model behaves in the situation of adjusting wind direction so that mean wave direction at near shore more or less the same with measurement. Description on that aspect is presented below.

- ***Discussion on the results of the case when putting different wind, wave direction at boundary***

In case the wind direction is adjusted so that a fair agreement between computation and measurement of mean wave direction in near shore can be obtained, results in *table 5-6* show that instead of the agreement of mean wave direction, the value of wave heights differ from measured data about 10 %, the peak wave period almost remain unchanged compared with approach 1. This means that no way to adjust the model in order to achieve the results they are consistent with measurement of all wave parameters such as wave height, peak wave period and mean wave direction nearshore if we don't have sufficient data for varying wind condition in the study area.

Comparing two alternatives, one for agreement of significant wave height H_s, and one for agreement of mean wave direction θ, it is deduced that the former alternative does not take time for adjusting the wind direction, but the mean wave direction neashore is not consistent with nature. The latter alternative can get well agreement of mean wave direction, in turn it requires more time to adjust wind direction, and significant wave height is still not consistent with the real situation. It is acknowledged that concerning the sediment transport, both factors of significant wave height and mean wave period are important to define the transport rate along the shore. However, one alternative has to be chosen for computations in chapter 6. Thus, it is decided to select alternative 1. The reason is that computation for yearly averaged wave data consists of 96 lines, this will require longer time if running in alternative 2. On the other hand, as mentioned earlier, alternative 1 predicts mean wave direction shifting more to the southward (wave coming from south direction) compare to measured data. It means that applying this alternative for computation of sediment transport would be more conservative since at present we are expecting the sediment transport computed by model is from north to south.

Finally, parameters set up for computations of mean statistical year wave data set shall include 500m grid size with nesting technique, third generation mode, constant boundary condition, uniform wind condition along with other default settings as mentioned in *chapter 4*.

5.3.4 Conclusions

In brief, the calibration of the model has been carried out in this section. The following conclusions were obtained:

- *The agreement between results from SWAN model and the measurements are fairly well for wave height.*
- *With respect to peak wave period, the agreement is still not proper. The possible reason for such inconsistent found is due to the error in the measure device. If the coming wave is too short, the measure device cannot register it. The long period measured was explained by the hypothesis that swell from SE direction with a long period can approach the shore and be recorded by the measure device. In this case the peak wave periods computed by the model seem to be more reliable.*
- *The prevailing parameter the mean wave direction is still a matte of restriction. This uncertainty of the model found is due to the assumption of uniform wind field in the computational grid. All the selected parameters set up will still be employed for future computations.*

Chapter 6

MODELLING OF NEARSHORE WAVES (SWAN) AND SEDIMENT TRASPORT (UNIBEST) FOR YEARLY AVERAGE WAVE CLIMATE

6.1 GENERAL

In the previous chapter, the SWAN wave model calibration has been treated and ending up to a set of parameters for the study area at Nam Dinh coast. This parameters set will be used for computing nearshore wave climate of mean statistical year at Nam Dinh coast based on the offshore wave data at Bach Long Vi Island. Then, as a requirement to evaluate longshore sediment transport rate using output from SWAN model, UNIBEST model has been used. The results from SWAN model runs are employed as the input for simulating of transport capacity along Nam Dinh coast by UNIBEST model. Finally, a comparison between two wave model approaches 1D and 2D will be made to investigate the influence of schematisation on nearshore wave climate calculation in the specific area at Nam Dinh coast.

All above tasks will be carried out and described thoroughly in the following sections.

6.2 NEAR SHORE WAVE MODELLING (SWAN)

When modelling wave induced long shore sediment transport capacity patterns along the coastline, a yearly average wave climate is needed as input for these computations. For that purpose, a series of wave computations in the coastline of Hai Hau have been performed using the parameters set-up. Summary of parameters are given in *table 6-1*.

Table 6-1. Parameters set-up for SWAN model application

Stationary mode
No current effect
Default settings for physical processes
Input bottom grid: 1000x1000m
Computational grid: 500x500m, Nesting grid
Third generation mode
Accuracy criterion: Standard, or adjust to converge for final solution
Constant boundary condition
Uniform wind field in computational grid

Description of all cases for yearly average wave climate were given in *table 4-9 – chapter 4*. It consists of 96 wave scenario in different wave heights H_s, peak wave periods T_p, mean wave directions θ and wind speeds. It should be noted that, all those wave scenarios cover in 9 directions from 45^o to 225^o with the sector size of 22.5 degree. An illustration 9 direction of coming wave at boundary is displayed in *App.6-1*. Waves coming from other directions are not taken into account since they are considered not to have influence on longshore sediment transport at nearshore. Data in *table 4-9* used as boundary condition together with parameters set up will formulate 96 wave simulations.

For each model run, results with various wave parameters are required at 11 locations in each depth contour from 2m to 10m. Such a typical output file is displayed in *Appendix 6-1*. These data will be helpful for computation of sediment transport capacity on various locations along the Nam Dinh coast. For the aim of this study, only wave height H_s, peak wave period T_p and mean wave direction θ at 3 locations just south of Red river mouth, at So river mouth and at the position just north of Ninh Co river mouth are extracted and tabulated in *Appendixes from 6-2 to 6-4.* Those positions are chosen since the coastline of Nam Dinh has a curved orientation; therefore different wave climates are to be expected in such critical locations.

6.3 UNIBEST MODELLING

6.3.1 Objective of UNIBEST Modelling

In order to derive the magnitude of sediment transport, a numerical model UNIBEST is adopted in this study. UNIBEST is an acronym of UNIform Beach Sediment Transport, developed by Delft Hydraulics. UNIBEST is a one-dimensional mathematical model, based on the single line theory. The UNIBEST version 5.0 released in February 1999 has been used in this project to compute the long-shore sediment transport.

6.3.2 Brief description of UNIBEST model

The UNIBEST software consists of 2 separate modules:

UNIBEST-TC : Designed for the computation of cross-shore transport and resulting beach changes induced by waves, tidal currents and winds.

UNIBEST-CL+ : Designed for the simulation of coastline changes due to longshore sediment transport gradients. The UNIBEST-CL+ consists of 2 integrated sub-modules:

- The Long-shore Transport module (LT-module)
- The Coast Line module (CL-module)

The required long-shore sediment transport calculations are computed by the LT-module. These transports are used by the CL-module to perform coastline evolution simulation in which effects of structures such as groynes, offshore breakwaters, and revetments can be incorporated.

In the frame of this thesis, only UNIBEST-LT will be used for calculation of longshore sediment transport at pre-specified locations. In general, as part of a more comprehensive evaluation for coastline evolution, the UNIBEST-CL module has to be carried out. However, within the scope of this thesis and due to time constrain, it is not the intention of the report to undertake such computation. Anyway, nearshore wave climate at a lot of locations along Hai Hau coast have been computed (It is not given all in this report) can be used as a reference for future computations of coastline change.

Longshore Transport (LT) module

The LT-module is designed to compute tidal and wave-induced longshore currents and sediment transports on a long-shore uniform beach with arbitrary profile.

In UNIBEST-LT, the surf zone dynamics are derived from a built-in random wave propagation and decay model (Battjes and Stive, 1984). The model transforms offshore wave data to the coast taking into account the principal processes of wave energy changes due to bottom refraction, shoaling, dissipation by wave breaking and bottom friction.

In the model, longshore current distribution across the beach profile is derived from the momentum equation along-shore, taking into account bottom friction, the gradient of radiation stress and the tidal surface slope along-shore.

The longshore sediment transport rate and its cross shore distribution are evaluated according to several total-load transport formulas for sand and shingle which enable a sensitivity analysis for local conditions.

The littoral transport can be represented by a user-defined grid, which can be adapted depending on the particular conditions of the situation to be studied. At each grid point, the sediment transport rate is computed for local hydraulic conditions. Following sediment transport formulae can be involved:

- CERC (1984)
- Bijker (1967, 1971)
- Van Rijn (1992)

The computational procedure may take into account any pre-defined wave climate and tidal regime in order to enable an assessment of gross and yearly transports, seasonal variation and even storm events.

6.3.3 Input data and model results

In *chapter 2*, all available data needed for this thesis was described. In order to run UNIBEST model, various parameters are required. An overview of input parameters for model runs is given *in table 6-2 to 6-4.*

Table 6-2. Tidal current information

Tidal height (m) relative to mean sea level	Velocity (m/s)	Frequency (%)
+1.56	0	25
0	-0.3	25
-1.56	0	25
0	+0.3	25

Table 6-3. The coefficients for the energy decay calculation

Coefficient for wave breaking (gamma) [-]	0.8
Coefficient for wave breaking (alpha) [-]	1
Coefficient for bottom friction (fw) [-]	0
Value of the bottom roughness (kb) [m]	0.1

Table 6-4. The coefficients for transport formula

Mass density of sediment (kg/m)	2650
D_{50} (µm)	157
D_{90} (µm)	200
The particle fall velocity (m/s)	0.02
Bottom roughness (m)	0.01
Criterion deep water, H_{sig}/h	0.07
Coefficient b deep water	2
Criterion shallow water, H_{sig}/h	0.6
Coefficient b shallow water	5

As mentioned in previous sub-section, along the project coastline only three locations are selected for further computation of sediment transport. They have been defined and located on the map as shown in the *figure 6-1*. The corresponding cross sections are taken from the measurement as illustrated in *App.2-2.* The outputs of wave parameters at 8m water depth from SWAN runs of 96 cases are employed as the wave information input for calculating the longshore sediment transport. They are given in *App. 6-3*.

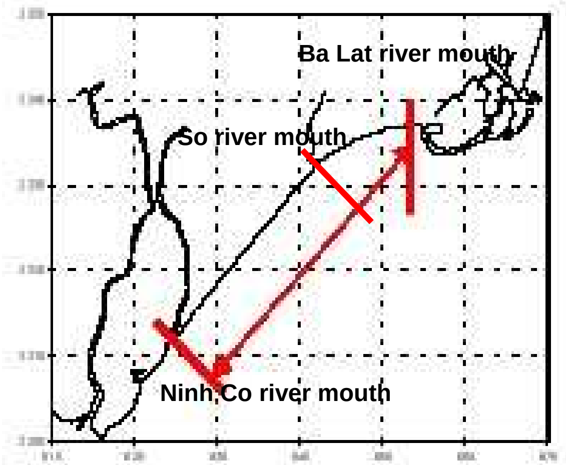


Figure 6-1. The map indicating 3 selected locations for longshore sediment transport computation along the project coastline

On the basis of Bijker formula the computations yield the sediment flux as shown in *figure 6-2 to 6-4.* The calculation of the sediment flux shown in *figure 6-2* was based on a coastline angle of 75 degrees. The calculations of the sediment flux shown in *figure 6-3 and 6-4* were based on a coastline angle of 42 degrees.

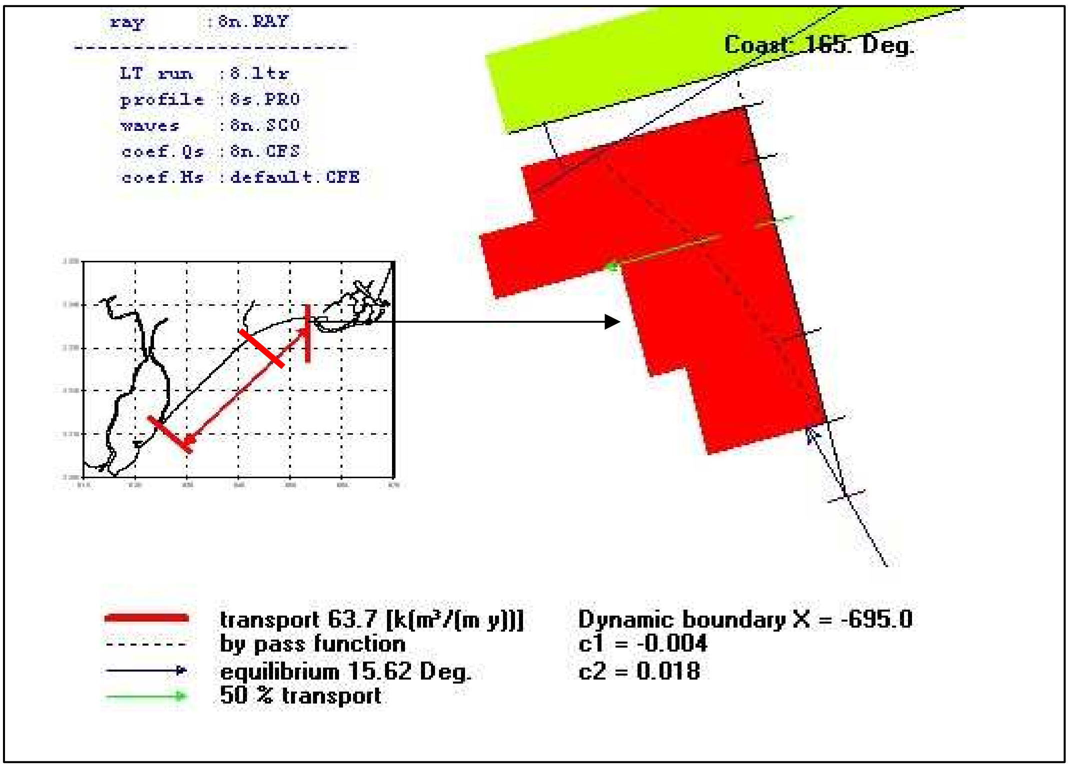


Figure 6-2. Long shore sediment transport at the south of Ba Lat river mouth

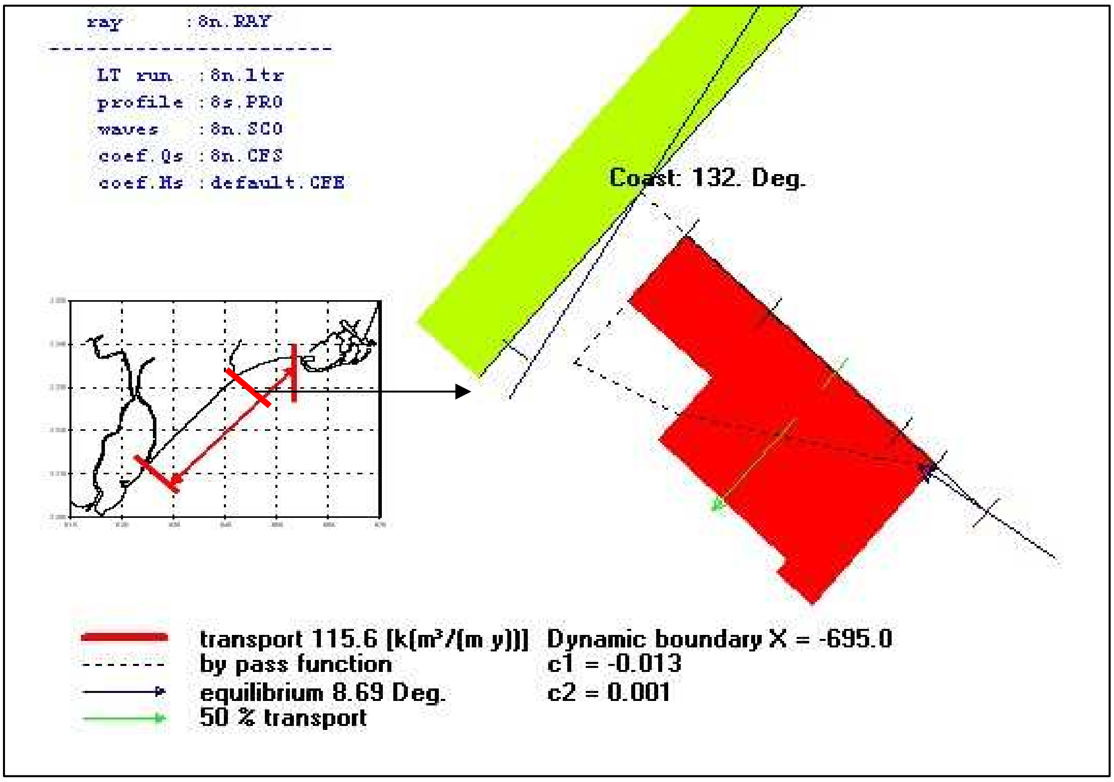


Figure 6-3. Long shore sediment transport at So river mouth

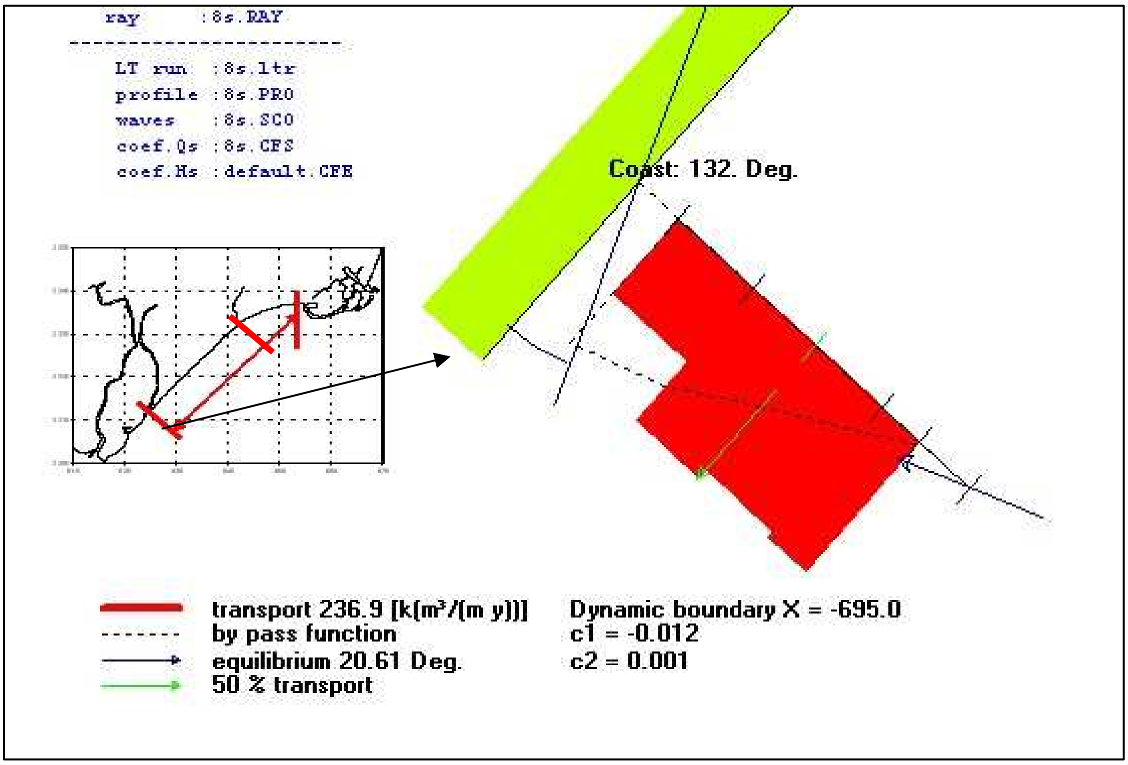


Figure 6-4. Long shore sediment transport at the north of Ninh Co river mouth

It can be observed from *figure 6-2 to 6-4* that longshore sediment transport computed by UNIBEST model using outputs from SWAN is southward going at all three locations and also the resultant net transport is southward going, increasing form north to south. This result is consistent with observation in terms of direction of sediment transport.

6.4 COMPARISON AND DISCUSSIONS

In this section, the influence of the modelled wave climate on the results of the longshore sediment transport calculation will be discussed.

As mentioned in *chapter 1*, conclusion from of Bas's thesis [7] is that a 1D wave modelling approach may lead to the wrong direction of sediment transport in Hai Hau coast. To get a deep insight of this existing restriction, and also to evaluate the performance of 2D wave model SWAN compared with 1D approach in this particular case, a brief description of 1D wave method in Bas's thesis will be given as follows.

Firstly, looking at the schematisation for 1D wave method as used in Bas's thesis.

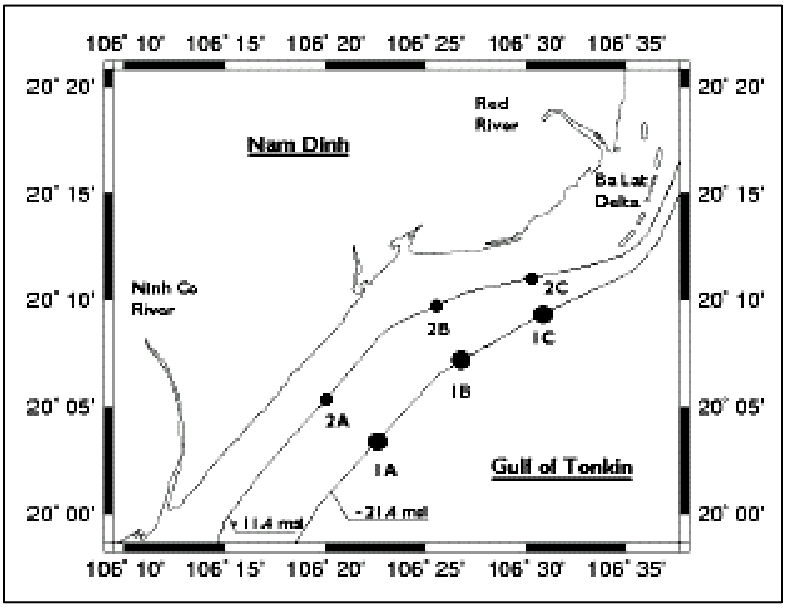


Figure 6-5. The schematisation of 1D wave modelling method

Initially, deep-water wave climate at 21.4 m depth contour is predicted by 1D WATRON model. Subsequently, from deep-water wave condition at 21.4m depth contour, refraction and shoaling calculation was applied to transform wave period, wave height and wave direction to 11.4m depth climate. The computations were based on energy conservation and the assumption that the sea bottom has straight and parallel contours. Consequently, the resulting sediment transport as computed did not correspond with the real situation. In detail, at location 2A (see *Figure 6-5*), northward going sediment transports were calculated while as already known by observation of coastal process and from Pruszak, et al. (2002) [10], the resultant net transport should be southward going.

The explanation for wrong direction of the sediment transport was found due to two reasons. First, one of feature of 1D WATRON model is if the wave approach almost in the same direction of the shore, by refraction its contribution is almost neglected. Therefore, the very important section of waves coming from 45 degrees to north was filtered out by the refraction calculations, causing the wave climate to be dominated by waves coming from the southern and eastern direction. Second reason is due to simple schematisation in 1D approach. Since the computations were carried out from 21.4m depth, in fact at that depth the 45 degrees wave might already refract at deeper water wave, changing to 60 degrees waves before approaching the shore, therefore it will have influence on nearshore climate.

The refraction factor *Kr* varies with bottom topography, tide level, period, and angle of incidence wave. Its determination requires numerical calculation for each individual case. The assumptions of bottom topography as straight and parallel contours make the coefficient *Kr* depend on only water depth *d* and wave condition in deep water. This remark is inferred from the equation:

$$K_R = \sqrt{\frac{\cos\theta_o}{\cos\theta}}$$, in which: θ_o is wave angle at deep water,

θ is wave angle at shallow water, $\theta = f(d, Lo, \theta_o)$

Irregular bathymetry can cause waves to be refracted in a complex way and produce significant variations in wave heights and energy along the coast. Thus, the result in 1D wave method will lose the accuracy in case of complex topography.

The prediction of wave field in the area where refraction occurs requires a calculation of wave rays and of energy. The rapid variations of the wave amplitude and directions can arise in refraction calculation, because each ray is calculated independently of the other rays and independently of the wave amplitude.

Detailed wave climate along the curved coastline in 1D wave method cannot give reliable results, thus it is the reason accounting for the wrong direction of sediment transport as mentioned. The use of 2D wave climate therefore can be expected to get better result since it can take into account of 2D effect by putting exact bathymetry of the Gulf of Tonkin in general and of the nearshore region in particular.

As mentioned in previous section, longshore sediment transport as computed by UNIBEST model using wave data from SWAN model at all three locations is southward going and also the resultant net transport is southward going, increasing form north to south. The result agrees well with the observed coastal processes at least in terms of direction of the transport.

In terms of transport rate, the magnitude of sediment transport as yielded from the UNIBEST model is less than estimated losses of sediment transport as shown in *figure 2-8*. For example, although the estimated loss in south of Ninh Co river mouth is 1.3 MT/year, model only manages to predict to about 0.7 MT/year. A possible reason may be related to the conclusion derived in *chapter 5*, it is that SWAN wave model in some extent estimate the mean wave direction as not corresponding well as reality due to the assumption of uniform wind condition in the entire computation grid. In fact, the mean wave direction at the nearshore may be influenced by the local wind effect, which is different from the wind condition at the offshore. Thus, the actual mean wave direction at the near shore may different from the result of the SWAN model. As a result, the computed capacity of sediment transport by UNIBEST model with such a near shore wave condition cannot consistent with the estimated loss.

6.5 CONCLUSIONS

- *In brief, the above comment showed that using the SWAN 2D wave model, the results of the nearshore wave climate in Nam Dinh coast appears to be better predicted than by the 1D wave method. The reason is that, SWAN can simulate all physical processes in general and refraction in particular when wave travel from offshore to the nearshore. This cannot be undertaken by a 1D wave approach as demonstrated in the previous study [7]. Although, the results still haven't been optimal, the author is aware of that drawback and would strongly suggest further study to investigate and obtain better results. Anyway, nearshore wave climate in Nam Dinh coast computed by the SWAN model in this study as extracted in App.6-2 to 6-4 can be used as a good reference for any future research regarding to this respect.*

Chapter 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 GENERAL CONCLUSIONS

This study was carried out to investigate the nearshore wave climate at the Nam Dinh coastline in order to be able to explain erosion problem along the coast.

According to former study (Bas, W., 2002), a 1D wave model for transforming the wave data from deep water to shallow water was not able to predict the coastal erosion adequately. In this study particular attention has been put on a 2D wave model approach using SWAN. The achievement from the study may be considered as documentation for future researches.

From the results of this study, one of the most important findings was the improvement in the pattern of sediment transport by applying a 2D wave model. If the 1D wave model approach resulted in a negative output of longshore transport compared to reality, the results of the 2D model approach was found to be able to reproduce the actual longshore transport direction at the study area.

Application of the SWAN model in the particular case at Nam Dinh coast was taken by adopting a number of assumptions. They include that:

- The influence of current is neglected
- Wind condition is assumed to be uniform in the computation grid.

The main reason to come up to such assumptions is due to the lack of data as mentioned in section 4-1.

The following detailed conclusions are obtained from the study:

- In the case presented in this thesis, analysis has demonstrated that a rectangular grid extending till Bach Long Vi island in the east, till the land in the north, south ward and rotate 45^o relative to the north seems to suggest the most reasonable grid and thus has been selected for model simulation. (Reference is made to 4-2-2)
- The SWAN run in stationary model was employed in this study. This is considered acceptable for most coastal applications since the residence time of the waves in the

computational area is expected to be far less than the time scale of variations of the wave boundary condition, the wind and the tide. (Reference is made to 4-1-2)

- In Nam Dinh coast, the spatial resolution of 500m with nesting technique generally is fine enough to predict wave condition. With this option the model results are more or less the same with measured data and time required for it is reasonable. (Reference is made to 5-2-1)

- Based on a comparison between a second and third generation mode it was decided to use the latter. However, this led to the convergence problems, solved by adjusting accuracy criterion. (Reference is made to 5-2-2)

- In this particular case, the option with uniform wave condition at boundary appears to be closer to the observed data, thus it was chosen. (Reference is made to 5-2-3)

- The agreement between the SWAN model and the measurements in terms of significant wave height is satisfactory. (Reference is made to 5-3)

- The computed peak wave period did not agree well with the measurement, but it seems to be better than measured data. A possible reason may be due to errors introduced by pressure transducer measurements. This measure device may not take into account the effect of shorter waves. Instead, only the longer wave components can be measured. (Reference is made to 5-3)

- It is acknowledged that the basic model set-up was not able to accurately reproduce the actual mean wave direction referred from available data. A possible explanation could be that the assumption of uniform wind field, which may be too crude to accurately simulate the model. (Reference is made to 5-3)

- The yearly average wave climate at Bach Long Vi island was transformed to the Nam Dinh coast using SWAN. Among various wave parameters and output points, only the magnitude of significant wave height H_s, peak wave period T_p and mean wave direction θ at three critical points along depth contours of 5, 8 and 10m were extracted and tabulated. These data would be used as a reference for future research concerning the Nam Dinh coastline. (Reference is made to 6-2)

- Results from the SWAN model were introduced into the UNIBEST model to simulate long shore sediment transport in Hai Hau coast. The direction of long shore sediment transport at three considered locations along Hai Hau coastline as computed is from north to south and increases from north to south, meaning that it is consistent with the observations. However, in terms of transport rate, the assessment may slightly underestimate the real situation. This could be due to the inaccuracies of wave direction obtained from SWAN. Another possible reason is related to cross-shore transport. Within the scope of this study, it is not the intention of the report to undertake such thorough investigation.

Generally, it can be concluded that SWAN can describe 2D effects adequately and leads to better result for wave climate at the near shore of Hai Hau coast. However, it can also be derived from the study that an advanced model also requires adequate and precise input data, otherwise the achieved results will be limited in the accuracy.

7.2 RECOMMENDATIONS

Based on this study the following recommendations have been formulated:

- Although SWAN is easily accessible through INTERNET, it is still not developed enough to be categorized as a user-friendly package. Therefore, when applying SWAN to a particular case study, the users have to apply own necessary pre- and post processing tools leading to inconvenient and time-consuming works. It is therefore recommended that further work is needed to create a more friendly user-interface.

- It is recommended that the proposed future studies should carry out more thorough research on the numerical scheme to increase the convergence speed when all physical processes (referring to third generation mode) are taken into account.

- As highlighted in the report, a uniform wind field was adopted in the model leading to inaccurate wave directions. Thus, in order to improve the performance of SWAN in wave predictions, it is recommended that wind data should be obtained and be used to generate a variable wind field in computational grids.

- The model calibration was carried out with short-term time series data. It would be better if measured long term nearshore wave data would be available so that calibration of the model could be done for a mean statistical year. In this way, the results of SWAN in the study area would be better. It is therefore recommended that in Nam Dinh coast, a platform to measure near shore wave data should be built permanent basis. Such a work would benefit not only researchers in the future but be very useful to solve the existing constrains in Nam Dinh coast related to the erosion problem.

REFERENCES

[1] Booij, N., Haagsma, IJ.G., Kieftenburg. A.T.M.M., Holthijsen, L.H., 2000.
SWAN implementation manual, Version 40.11. http://swan.ct.tudelft.nl

[2] Holthuijsen, L.H., 2001.
Ocean waves, lecture note prepared for IHE Delft

[3] Bouwmeester, E.C., Barijes, J.A., 2002.
Short waves, lecture note prepared for IHE Delft

[4] Ninh, P.V., Hung. P.N., 2002.
Mechanism of the erosion problem of Red River Delta coastal line

[5] Anonymous, 1984.
Shore Protection Manual, volume1. USA Army Engineer and Development Centre, Vicksburg, Mississippi, USA.

[6] Heb-IHE, 2002.
Coastal erosion analysis of Nam Dinh coast and proposed solutions. Final report for Group work at IHE.

[7] Bas Wijdeven, 2002.
Coastal erosion on a densely populated delta coast – A case study of Nam Dinh province, Red River Delta, Viet Nam. Msc thesis, Delft University of Technology, The Netherlands.

[8] Cuong, N.T., 2001.
Annual report of Nam Dinh province.

[9] Hung, N.M., Ninh, P.V., Larson, M., Hanson, H., 2001.
Regional wave transformation and associated shoreline revolution in the Red River Delta, Viet Nam. Wave 2001, 4th international symposium on ocean waves measurements and analysis. Sept.2-6,2001, SanFrancisco.

[10] Pruszak, Z., Szmytkiewicz, M., Hung, N.M., Ninh, P.V., 2001.
Coastal processes in the Red River Delta, Viet Nam.

[11] Ris, R.C., 1997.
Spectral wave modelling of wind waves in coastal areas. Report N^{o}97-4. Department of Civil Engineering, Delft University of Technology.

[12] WL/Delft Hydraulic, 1999.
UNIBEST_CL+vs 5.0 for Window user manual.

[13] WL/Delft Hydraulic, 1997.
Delft3D-RGFGRID and QUICKIN, User manual.