

# Fast Simulation of Wind Waves along the Korean Coast Induced by Typhoon Nabi, 2005

## 태풍 나비에 의한 한국 연안 태풍파의 신속 모의

Jung Lyul Lee, Heung Soo Lim

이정렬\*, 임흥수\*\*

---

### Abstract

An efficient typhoon wave-generating model is applied to northeast Asia sea zone presented that can be used by civil defense agencies for real-time prediction and fast warnings on typhoon-generated wind wave and storm surge. Instead of using commercialized wave models such as WAM, SWAN, the wind waves are simulated by using a new concept of wavelength modulation to enhance broader application of the hyperbolic wave model of the mild-slope equation type. The results simulated along the Korean coasts during Typhoon Nabi (2005) showed reasonable agreement with the recorded wind waves.

*Key words* : Typhoon Waves, Typhoon Nabi, Korean Coasts, Mild-slope Equation

---

### 1. Introduction

The actual storm surges by typhoons are often ranged from 1 to 3m. However, the effects of overwash produce high water levels twice and more along the shore. For civil and coastal engineers, therefore, accurate prediction of the typhoon waves is critical in their structural design and mitigation plan. Therefore, we have developed a wind-wave model of hyperbolic type embedded in a depth-integrated circulation model to predict more accurately the storm waves generated by typhoons in northeastern Asia.

The main objective of the present study is to apply a new wave model to typhoon-affected sea area instead of using commercialized wave models such as WAM, and SWAN. We are also interested in examining the validity of the model for simulating storm waves by comparing the simulated results with the recorded field data during Typhoon Nabi (2005).

### 2. Typhoon Wave Model

Recent advances in the physics of numerical wave prediction models (Komen et al., 1984;

---

\* 정회원 \* 성균관대학교 토목환경공학과 교수 \* E-mail : jllee@skku.edu

\*\* 학생회원 \* 성균관대학교 토목환경공학과 석사과정 \* E-mail : frogman@skku.edu

Hasselmann et al., 1985) have enabled the development of operational hurricane prediction models that yield results consistent with increasing field database (Young, 1987; Booij et al., 1999). Due to the complexity of these models, however, they are computationally expensive so that it is currently not feasible to apply such models in the warning system. Here we propose a very simple and yet sufficiently accurate wind wave model.

For storm wave generation, the forcing source is the surface shear stress generated by wind. During a typhoon event, usually only a finite number of parameters at a limited number of locations can be measured in the field. Therefore, a mathematical model for describing the entire wind field based on the limited field data is necessary. These mathematical models are often based on the following parameters: the central pressure, maximum wind, radius to the maximum wind as well as other parameters. In the present study, we will employ the Holland model (Holland, 1980 Bode and Hardy, 1997) commonly used for describing the wind and pressure field.

The Holland model is given as

$$P(r) = P_c + (P_\infty - P_c)e^{-(R/r)^B} \quad (1)$$

$$W(r) = \left[ \frac{B}{\rho_a} \left( \frac{R}{r} \right)^B (P_\infty - P_c) e^{-(R/r)^B} + \left( \frac{rf}{2} \right)^2 \right]^{1/2} - \frac{rf}{2}, \quad 1.0 < B < 2.5 \quad (2)$$

where  $P$ ,  $P_c$  and  $P_\infty$  are the local, central and unperturbed pressures, respectively,  $R$  is the radius to maximum winds,  $W$  the wind speed,  $f$  the Coriolis coefficient. In the shallow water equations, the forcing term directly related to wind is the shear stress  $\tau_s$  generated at the water surface due to wind as

$$\tau_s = (\tau_{sx}, \tau_{sy}) = C_{10} \rho_a |U_{10}| U_{10} \quad (3)$$

where,  $\rho_a$  the air density, and  $C_{10}$  the drag coefficient which is given by  $10^3 C_{10} = 0.8 + 0.065 U_{10}$  (Wu, 1982) and  $U_{10}$  the wind speed at a height of 10 m above the mean sea level which is calculated by

$$U_{10} = KW(r), \quad K = 0.8 \quad (4)$$

The mild-slope equation (MSE) developed by Berkhoff (1972) has not only been used in its original form of an elliptic equation but also provided the basic governing equation for the development of other wave equations such as the parabolic equation, hyperbolic equation, and elliptic equation of phase averaged type. The linear version of mild-slope equation proposed by

Lee and Park (2001) is used in this study:

$$\frac{\partial^2 \eta}{\partial t^2} + \nabla \cdot \left( CC_g \frac{1}{g} \frac{\partial \mathbf{u}}{\partial t} \right) + \left( \sigma^2 - k^2 CC_g \right) \eta = 0 \quad (5)$$

$$\frac{\partial \mathbf{u}}{\partial t} + g \nabla \eta = 0 \quad (6)$$

It is noticeable that Eqs. 5 and 6 allow the wave energy to propagate with a group velocity differently from the Copeland (1985)'s wave model. Similarly as done by Madsen and Larsen (1987) for regular waves, the above equations are reformulated by extracting the harmonic time variation by letting  $\eta = S \exp(-it)$  and  $\mathbf{u} = \mathbf{U} \exp(-it)$  so as to accelerate the solution considerably since one does not need to resolve the wave period any longer.

$$\frac{\partial^2 S}{\partial t^2} - 2i\sigma \frac{\partial S}{\partial t} + \nabla \cdot \left[ \frac{CC_g}{g} \left( \frac{\partial \mathbf{U}}{\partial t} - i\sigma \mathbf{U} \right) \right] - k^2 CC_g S = S_i \quad (7)$$

$$\frac{\partial \mathbf{U}}{\partial t} - i\sigma \mathbf{U} + g \nabla S = \mathbf{U}_s \quad (8)$$

where  $S_i$  is the source term which generates the wind waves. The source term is given in terms of the wind stress on the grid mesh of  $x$  and  $y$ . The wave heights generated by wind impacts are assumed to be proportional to the wind shear stress and their directions are also assumed the same as those of winds. Details of numerical schemes including the treatment of boundary conditions are described in Lee (1998).

Since the grid space is too wide for predicting short wind waves by a phase-resolving wave model, we simply enlarge the wavelength with increasing wave period without changing the phase speed and the group velocity calculated under wave conditions of the original period. Then the wave refraction and wave shoaling effects can be maintained but wave diffraction is overestimated due to the enlarged wavelength. Even in typical wind wave models, however, the wave diffraction is troublesome. Fortunately, the effects of wave diffraction in the open ocean are often negligible.

Hurricane Iniki was initially formed as a tropical depression near (12°N, 135°W) on September 5, 1992. With its sustained maximum wind continuing to increase, Iniki was upgraded to tropical storm and hurricane on September 7 and 8, 1992, respectively. On the afternoon (around 3 pm local time) of September 11, 1992, Hurricane Iniki made landfall on the southwest coast of Kauai Island and affected three Hawaiian islands causing severe property damage due to its high winds and the associated coastal flooding, particularly in Kauai. Causing total losses of \$1.6 billion, Iniki has been ranked as one of the most costly hurricanes in the U.S. history.

Compared with earlier hurricanes in Hawaii, Hurricane Iniki is relatively well documented. The available field data include wave height recorded by four buoys near Hawaiian islands. The wave, wind and surge data recorded by these buoys and tidal gages are valuable for

validation of hurricane wave and storm surge simulation models.

The computational domain for the present simulation is a large region of the Pacific Ocean that covers the coastal waters of Hawaii (see Figure 1). A grid system of  $242 \times 242$  with a coarse grid size of  $9,276\text{m} \times 8,712\text{m}$ , and a computational time step of 20min were used. Runs were commenced with the weak hurricane of central pressure 992mb from an initial calm state.

The measured data for hurricane trajectory, central pressure  $P_c$ , and maximum wind  $W_{max}$  were obtained from the survey report on Hurricane Iniki prepared by the National Weather Service, NOAA (1993). Our simulation results show that the maximum wave height occurred near maximum wind area of the right rear quadrant from the direction of forward movement as shown in Figure 1. This pattern is quite similar to that of standardized significant wave field for slowly-moving hurricane presented by Bretschneider (1966).

The computed and observed surge heights are given in Figure 6 for two locations: Haeundae, Busan and Sungsan, Jeju. Agreement between the present model and the buoy-recorded data is quite good, with time of peak wave conditions as shown in Figure 5 although the wind field was generated by a parametric model. In view of possible errors in storm parameters and track location, the present wind wave model performs quite well. As shown in Figure 4, the wave heights in the vicinity of a hurricane eye appear to be underestimated. With use of multi-period bands the model may provide the better results.

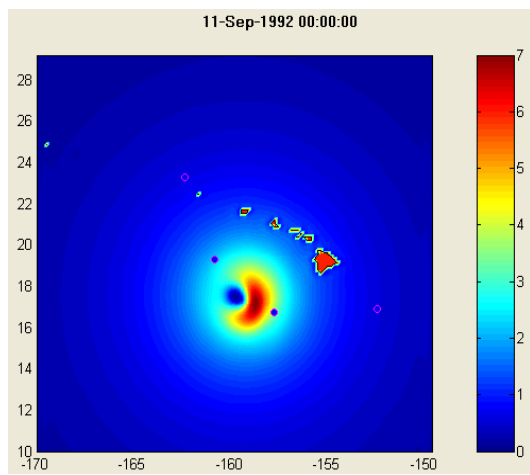


Fig 1. 개방된 해역에서의 태풍파 분포

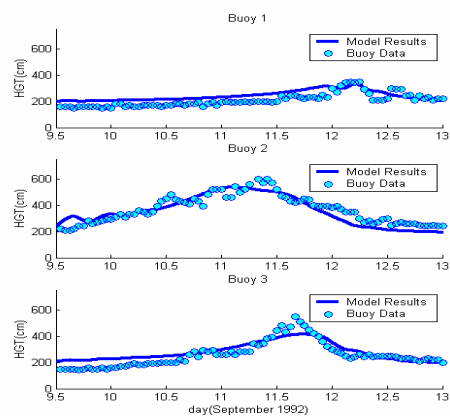


Fig 2. 허리케인 INIKI(1992)에 대한 관측치와의 비교

## 2. System

유비쿼터스 시대를 맞이하여 수치예보시스템을 활용하여 해상예측능력을 향상시키는 데 큰 관심을 모으고 있다. 새로운 초고속 모델의 개발과 차세대 고분해능 지역모델의 개발을 통하여 피해 예상 지역에 국한된 정밀 예보 시스템의 조속한 수립이 필요하며 충분한 모의실험 후 신뢰성이 확보되면 피난 경보 시스템의 주축으로 활용되어 제로 인재의 방재 시스템이 구축되기를 기대한다. 그러나 수치예보시스템이 적합한 유비쿼터스 활용 기술로 인정받기 위해서는 다음 4가지 전제

조건이 필요하다.

1. 신속한 결과 도출이 가능한 계산의 신속성
2. 비전문가도 사용이 편리한 기술의 편리성
3. 믿고 따를 수 있는 고분해 결과의 신뢰성
4. 필요한 모든 정보를 손쉽게 주고받을 수 있는 정보의 교류성

이 조건들이 만족되면 산출된 결과를 다양하게 재생산하여 정보를 필요로 하는 이용자는 물론 피해를 받을 수 있는 일반인들에게도 유비쿼터스 기반 기술을 통하여 다양한 방법으로 전달이 될 수 있다.

본 논문에서 소개하는 태풍과 모형 WIWAM 모형은 하루 동안의 태풍과 모의 계산에 일반 PC에서도 2-3분이 소요되고 GUI 기법을 이용하여 stand alone 형태로 완성되어 비전문가도 편리하게 설치하고 사용할 수 있다. 또한 피해가 예상되는 지역에 손쉽게 nesting이 되므로 보다 정밀한 결과를 제공받을 수 있다. 보다 정확한 결과를 도출하기 위해서는 보다 유용한 정보와의 연계가 중요한데 본 모형은 MATLAB으로 프로그램되어 쉽게 주 모형 시스템과 다양한 형태와 option으로 연계가 가능하다.

본 연구에서는 계획 중인 모니터링 시스템과의 연계를 통하여 신뢰성 있는 예보 시스템을 구축하고자 한다. 그리하여 U-Port를 구현하기 위한 기본 전략으로 매년 태풍의 영향권 내에 진입하는 부산항에서의 태풍과 피해를 저감하고자 한다. 부산항 태풍과 모의를 위한 광역 계산 영역은 그림 3과 같이 북위 24도로부터 52도, 동경 117도로부터 142에 해당되는 해역으로 중국 동부, 한반도, 일본 영토, 대만 일부를 포함하며 156×168 격자망에서 계산된다.

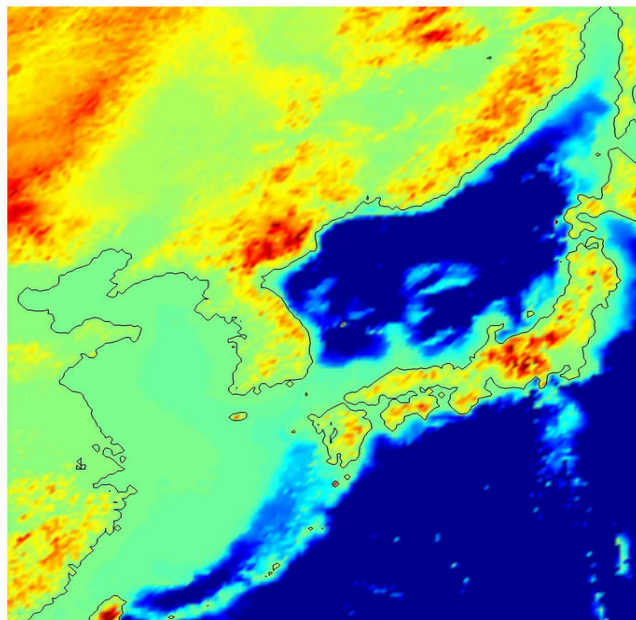


Fig 2. 계산 영역

신속한 예측을 위하여 임의 태풍에 대한 바람장 및 압력장은 예상 도달 위치를 따라 마우스로

클릭하고 사용되는 바람장 및 압력장 모형에 따라 기본 입력 자료를 입력한다. 수정 및 삭제가 용이하고 저장하여 나중에 신속히 새로운 경로에 대하여도 활용될 수 있다. 계산이 신속하므로 경로의 예상되는 확률 치로부터 태풍과교를 확률적인 정보로 산출하는 것도 가능하다.

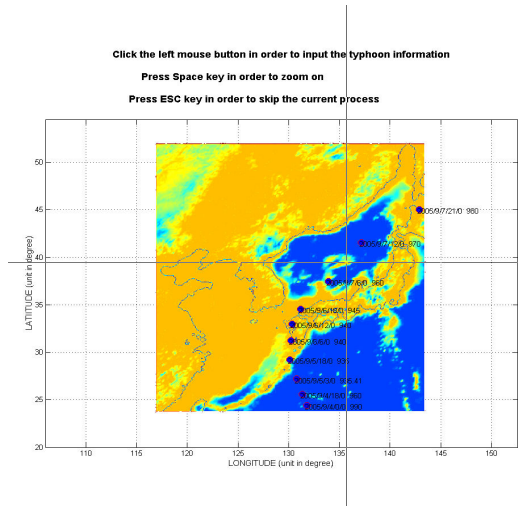


Fig 3. 태풍 나비에 대한 경로입력 예

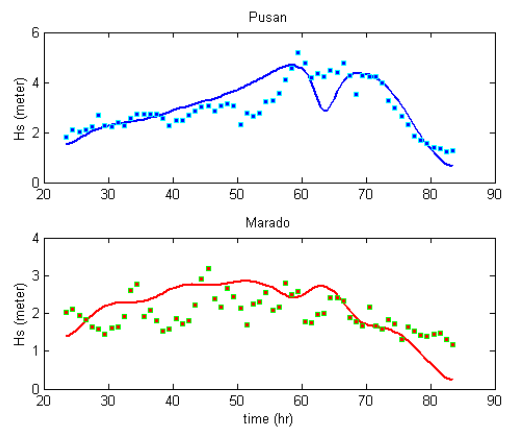


Fig 4. 관측치와의 비교

태풍 나비(2005)에 대한 모형 결과가 부산 해운대 및 마라도 관측 자료와 그림 5에 비교되었다. 근사적인 바람장 모형을 이용한 결과치고는 만족할만한 경향을 보이고 있어 앞으로 더 보정 작업을 수행하면 충분한 예측 능력이 확보되리라 사료된다. 주어진 태풍 예상 경로를 따라 계산되고 있는 결과가 그림 5에 도시되었다. 아직 보정 중이지만 모의되는 시점에서의 조위 및 조류도 자동 연계될 예정이다.

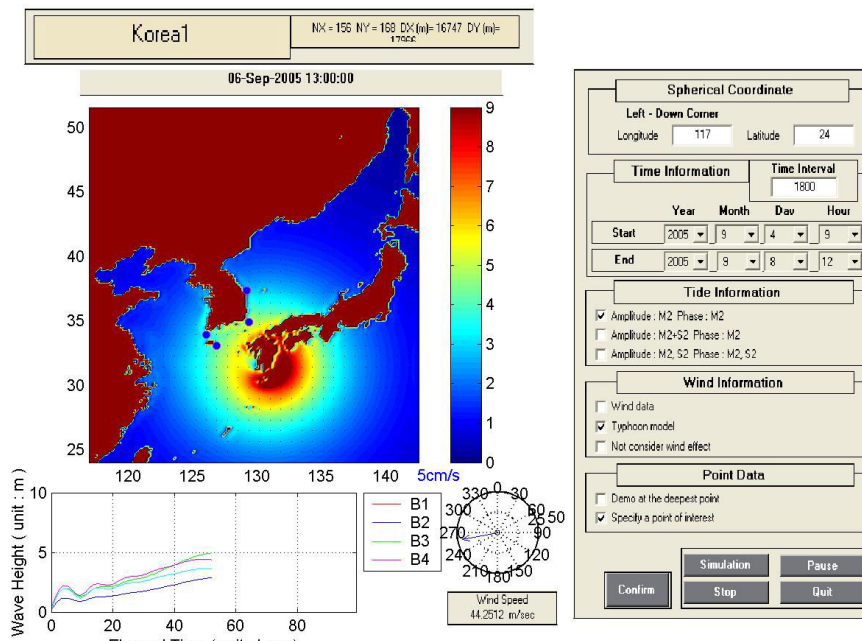


Fig 5. 태풍 NABI(2004)에 대한 태풍파 모의

#### 4. Conclusion

The fast computing wind wave model by applying a new concept was applied to Hurricane Iniki (1992) in Hawaii. The simulated surge and wave heights were compared with the recorded data. The model was found to be in good agreement and shows that the model is able to predict hurricane-generated wind waves. In addition, our study revealed that the hurricane-generated waves are much higher than the hurricane-generated storm surge during Iniki. These results are specifically applicable to the Pacificinsular environment where coastal bathymetry is usually very steep. For storm surge generated by hurricanes over gradually sloped continental shelves, where hurricanes may remain for a much longer time period, the storm surge can be significantly higher.

It is important to note that the present model is suitable to use by civil defense agencies as the warning system because it takes only a few minutes CPU time for 1day real time prediction on a normal PC. Obviously with use of multi-period bands the model can provide the temporal and spatial variations of peak frequency as well as the better results.

#### 감사의 글

태풍 NABI에 의한 태풍파 관측 자료를 기꺼이 제공해주신 해양연구원 이동영 박사님께 감사드립니다.

#### Reference

1. 이정렬 (1996). 광역에 적용가능한 포물선형 파랑모형. 한국해양·해양공학회지, 8(3): pp. 246-255.
2. Bode, L. and Hardy, T.A. (1997). Progress and recent development in storm surge modeling. *Journal of Hydraulic Engineering*, 123(4): 315-331.
3. Bretschneider, C.L., (1966). Wave Generation by Wind, Deep and Shallow Water, (in) Ippen, Arthur T., (ed.), *Estuary and Coastline Hydrodynamics*, New York: McGraw-Hill Book Company, Inc. pp. 133-196.
4. Holland, G.J. (1980). An Analytical Model of the Wind and Pressure Profiles in Hurricanes, *Monthly Weather Review*, 108: pp. 1212-1218.
5. Lee, J.L. and Park, C.S. (2001). A weakly nonlinear wave model of practical use, In: *Proc. of 4<sup>th</sup> international symposium waves 2001*, Ed. B.L. Edge and J.M. Hemsley, Vol. 1: pp. 894-903.
6. Lee, J.L. and Teng, M.H. (2004). High-frequency portion of wind-wave spectra in the presence of currents in a shallow sea. *Oceanology*, 18(3): pp. 267-270.