

Global Research Internship (GRI) Internship and Research Report Summer 2026

*Evaluation of spatial resolution effect on offshore wave hindcast
using a nested spectral wave model during a winter storm swell event*

冬季暴風時のうねり事例におけるネスティング波浪モデルを用いた沖
合波浪追算に対する空間解像度の影響評価

Nagoya University – Graduate School of Engineering

Civil and Environmental Engineering

Coastal Engineering Laboratory – Advisor: Nakamura Tomoaki

Doctoral Course First Year Student: Mustaqim Rahim

Host Institute: PARI_波浪研究グループ

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1 Background and Challenges

Coastal areas are continuously exposed to energetic wave conditions generated by severe weather systems, particularly during winter storms. These extreme wave events can affect coastal infrastructure, navigation safety, and marine activities, making accurate estimation of offshore wave conditions essential for coastal hazard assessment and risk management.

SWAN (Simulating WAVes Nearshore), developed at Delft University of Technology (TU Delft), is a spectral wave model widely used to simulate wave generation and propagation. In real ocean conditions, waves consist of numerous interacting wave components with different frequencies and directions, making it impractical to reproduce each individual wave directly over large spatial domains. SWAN simplifies this complex sea state by representing irregular waves as a directional wave energy spectrum and solving the wave action balance equation to describe the evolution and propagation of wave energy in space and time.

One of the major challenges in numerical wave modelling using SWAN is determining an appropriate spatial resolution for representing wave conditions from large-scale oceanic regions to coastal areas. Coarse-resolution models are computationally efficient and suitable for describing large-scale wave systems, but they may not adequately resolve smaller-scale bathymetric features and local wave transformations near the coast. In the investigated winter storm event near Kashima Port on 8–9 January 2020, the local model reproduced the general temporal variation of wave period and wave direction but underestimated the observed peak significant wave height. The simulated peak significant wave height was approximately 2.34 m compared with 3.73 m from NOWPHAS observations, indicating that further improvement of the model configuration was necessary.

In this research, a nested approach was applied to progressively increase the spatial resolution from the global scales toward the coastal area around Kashima Port. Higher-resolution detail models were developed to investigate whether finer spatial representation could improve the simulation of offshore wave conditions during the selected winter storm

swell event. The findings of this research are expected to contribute to a better understanding of how spatial resolution affects offshore wave hindcast accuracy during extreme swell events.

Key words: SWAN; Offshore Wave Hindcast; Nested Spectral Wave Model; Spatial Resolution; Winter Storm Swell

Note: The reason why I selected the Institution will be mentioned on chapter 3- Basic information of my GRI host institution

2 The objective of the internship

The purpose of this internship was to understand the fundamental concepts of spectral wave modelling and to evaluate the performance of offshore wave hindcast simulations during a selected winter storm swell event. First, operational hindcast products were analyzed to understand how well the simulated wave conditions reproduced the observed wave characteristics. After that, higher-resolution simulations were performed using a nested spectral wave modelling approach to investigate whether increasing the spatial resolution could improve the representation of offshore wave conditions.

The main objective of this study was to assess the influence of model resolution on several wave characteristics, including significant wave height, wave period, wave direction, directional spectrum, frequency spectrum, and directional wave spectrum. Through comparison among the local and higher-resolution detail models, this internship aimed to clarify which wave parameters are sensitive to spatial resolution and to identify the benefits and limitations of increasing model resolution for offshore wave hindcast during a winter storm swell event.

3 Basic Information of my GRI Host Institution

3.1 Introduction of PARI

The Port and Airport Research Institute (PARI) is a research institute under the National Institute of Maritime, Port and Aviation Technology (MPAT), Japan. PARI conducts research and technological development related to ports, coastal areas, and airports, with the aim of supporting the development, maintenance, safety, and resilience of maritime and aviation infrastructure. Its research activities cover a broad range of topics, including coastal engineering, marine environments, geotechnical and structural engineering, and advanced information systems.

Research related to coastal and ocean engineering is mainly conducted within the Coastline and Marine Fields, which include several specialized research groups such as the Wave Group and the Tsunami and Storm Surge Group. The Wave Group focuses on wave-related phenomena and technologies relevant to ports and coastal areas. PARI also operates large-scale experimental facilities for investigating wave propagation and coastal processes, including the Random Sea and Coastal Wave Basin, where offshore waves and their transformation due to coastal bathymetry and breakwaters can be reproduced.

During this internship, I joined the Wave Group and conducted numerical research on offshore wave hindcasting. The internship focused on spectral wave modelling and the influence of spatial resolution on simulated wave characteristics using a nested modelling approach. This research experience provided an opportunity to understand both the fundamental theory of spectral wave modelling and its practical application to coastal and offshore wave prediction.

3.2 The reason why I selected the Institutions

I selected the Port and Airport Research Institute (PARI) because it provides an opportunity to deepen my experience in numerical modelling for coastal and ocean engineering. I already had experience in applying numerical models in my previous research;

however, I wanted to understand numerical modelling beyond simply preparing input data and analyzing simulation outputs. I was interested in learning more about how a numerical model actually works, including its fundamental governing equations, numerical formulations, computational processes, and how physical phenomena are represented within the model.

PARI, particularly the Wave Group, provides an appropriate research environment for developing this deeper understanding. During the internship, I had the opportunity to study the fundamental concepts and governing equations of spectral wave modelling, examine how SWAN calculates the generation and propagation of wave energy, and understand the structure of nested wave simulations from global to detailed domains. In addition, I was able to learn about computational techniques used to improve numerical efficiency, including parallel computing for handling large computational domains and high-resolution simulations. This experience allowed me to strengthen not only my ability to use numerical models, but also my understanding of the physical, mathematical, and computational principles behind them.

4 GRI period

Table 4-1 GRI period details

Date	Place	Detail
2026/07/27	<i>PARI, Yokosuka</i>	<i>Orientation, Introduction to spectral wave modelling, Concept of nested model, and Laboratory tour</i>
2026/07/28	<i>PARI, Yokosuka</i>	<i>Global, Regional, and Local Model Setup, Analysis, and Python Visualization</i>
2026/07/29	<i>PARI, Yokosuka</i>	<i>Global, Regional, and Local Model Setup, Analysis, and Python Visualization</i>

2026/07/30	PARI, Yokosuka	<i>Discussion and analysis of the different wind forcing effect results to the spectral wave characteristics. Organize calculation results and preparation of reports (part1)</i>
2026/07/31	PARI, Yokosuka	<i>Discussion and analysis of the different wind forcing effect results to the spectral wave characteristics. Organize calculation results and preparation of reports (part2)</i>
2026/08/03	PARI, Yokosuka	<i>Introducing PARI research group Detailed Model Setup, Parallel Computing for High-Resolution Simulation, Troubleshooting of error</i>
2026/08/04	PARI, Yokosuka	<i>Detailed Model Setup, Parallel Computing for High-Resolution Simulation, Troubleshooting of error</i>
2026/08/05	PARI, Yokosuka	<i>Discussion and analysis of the spatial resolution effect results to the spectral wave characteristics. Organize calculation results and preparation of reports (part3)</i>
2026/08/06	PARI, Yokosuka	<i>Preparation for oral presentation</i>
2026/08/07	PARI, Yokosuka)	<i>Fill out impression and questionnaire forms.</i>

5 Achievement of results of the internship

5.1 Results of Winter Storm Visualization

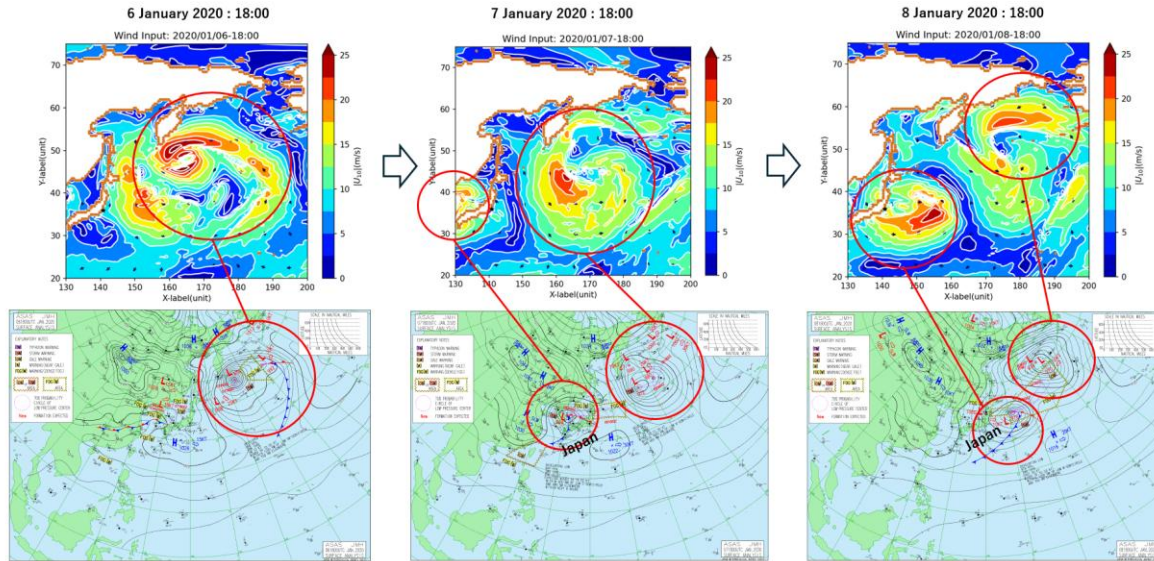


Figure 5- 1 Winter storm evolution from 6 to 8 January 2020 based on the Global Model wind forcing and JMA ASAS surface weather charts.

A winter storm developed over the North Pacific during 6–8 January 2020 and produced strong wind conditions over a broad area. On 6 January, a strong low-pressure system was located over the North Pacific. The system then moved eastward on 7 January, while another low-pressure system developed closer to Japan. By 8 January, the second system had intensified and approached Japan, producing strong winds that likely contributed to the generation and propagation of swell toward the study area.

The development of these pressure systems is compared with the simulated wind field in Figure 5.1. The simulated results generally reproduce the location and movement of the low-pressure systems shown in the JMA ASAS surface weather charts. Although some differences can be observed in the detailed wind distribution, the overall storm development is represented consistently. This suggests that the wind forcing used in the Global Model reasonably captures the main characteristics of the winter storm event.

5.2 Results of Global, Regional, and Local Model Comparison

A nested modelling approach was applied to progressively increase the spatial resolution around the study area. The simulation began with the Global Model, which used the coarsest spatial resolution. Its output was then transferred as the spectral wave boundary condition for

the Regional Model. The Regional Model subsequently provided the boundary condition for the Local Model, which was further nested into three higher-resolution Detail Models.

As summarized in Table 5.1, the spatial resolution increased from $1/2^\circ$ in the Global Model to $1/2048^\circ$ in the finest Detail Model. The model configuration was also refined through the nesting process. GSM wind forcing was used in the Global Model, while MSM wind forcing was applied to the Regional, Local, and Detail Models. In addition, higher-resolution bathymetric data at the hundred-meter scale were applied in the Detail Models, allowing smaller-scale seabed features and micro-topographic variations to be represented more clearly.

Table 5- 1 Model configuration for the nested spectral wave simulations

No.	Model Case	Resolution	Spectral Wave Boundary	Wind Forcing	Bathymetry
1	Global Model	$1/2^\circ$	—	GSM	GEBCO
2	Regional Model	$1/16^\circ$	From Global Model	MSM	JTOPO30
3	Local Model	$1/32^\circ$	From Regional Model	MSM	JTOPO30
4	Detail Model 1	$1/128^\circ$	From Local Model	MSM	M7000-Series
5	Detail Model 2	$1/512^\circ$	From Detail Model 1 ($1/128^\circ$)	MSM	M7000-Series
6	Detail Model 3	$1/2048^\circ$	From Detail Model 2 ($1/512^\circ$)	MSM	M7000-Series

The Global, Regional, and Local Models used two different bathymetric datasets. The Global Model used GEBCO bathymetry, while the Regional and Local Models used JTOPO30. The original GEBCO dataset has a spatial resolution of 60 arc-seconds, approximately 1.85 km, whereas JTOPO30 has a finer resolution of 30 arc-seconds, approximately 900 m. These datasets were interpolated onto the corresponding computational grids of the Global, Regional, and Local Models.

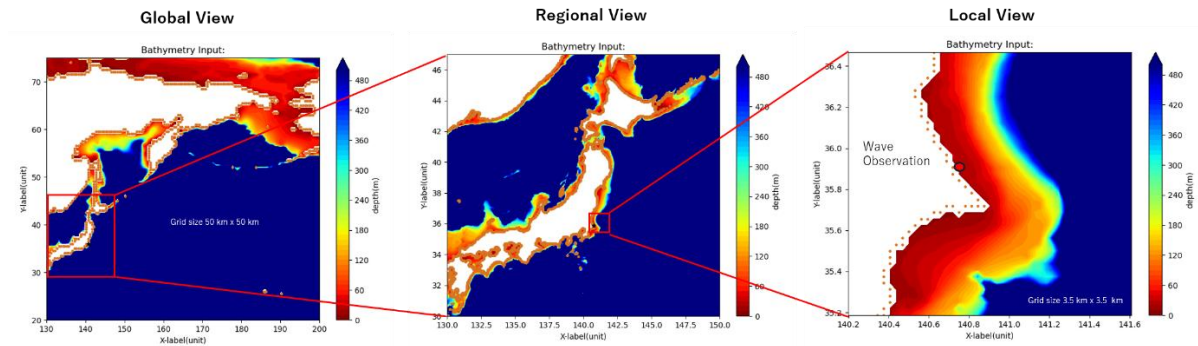


Figure 5-2 Comparison of bathymetric representation in the Global, Regional, and Local Models.

Wind forcing is an important input in the spectral wave modelling system because it directly influences wave generation and development over the computational domain. The wind data used in this study were obtained from the Japan Meteorological Agency (JMA). As illustrated in Figure 5.3, the simulated wind field during the peak of the storm event on 9 January 2020 represents a strong low-pressure system associated with the Aleutian Low over the North Pacific. The strong wind field generated by this system extended over a broad area and contributed to the development of long-period swell propagating toward the east coast of Japan.

Different wind datasets were applied according to the spatial scale of each model domain. The Global Model used the Global Spectral Model (GSM) dataset, which has an original grid spacing of approximately 20 km and was provided at 6-hour intervals. The Regional and Local Models used the Meso-Scale Model (MSM) dataset, which provides a finer spatial resolution of approximately 5 km and a temporal resolution of 1 hour. The use of MSM in the smaller-scale domains allows the wind field around Japan and the study area to be represented in greater spatial and temporal detail compared with the GSM forcing used in the Global Model.

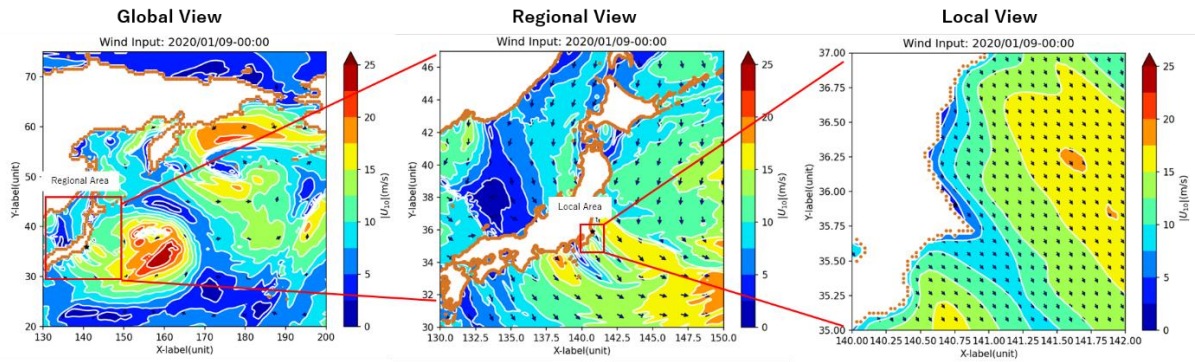


Figure 5- 3 Wind field representation in the Global, Regional, and Local Models during the peak storm event on 9 January 2020.

The simulated Significant Wave Height (H_{sig}) shows a clear difference between the Global Model and the Regional and Local Models. As shown in Figure 5.4, the Global Model generally produces lower wave heights near the study area, whereas the Regional and Local Models reproduce higher H_{sig} values and show similar spatial distributions around Kashima. This indicates that the transition from the Global Model to the smaller-scale domains has a noticeable influence on the simulated wave field.

The main differences in model configuration are summarized in Table 5.2. In addition to the increase in spatial resolution, the Global Model differs from the Regional and Local Models in terms of wind forcing, bathymetric data, and spectral boundary conditions. Therefore, the difference in H_{sig} between these model groups cannot be attributed solely to spatial resolution, but should be interpreted as the combined effect of the nested model configuration.

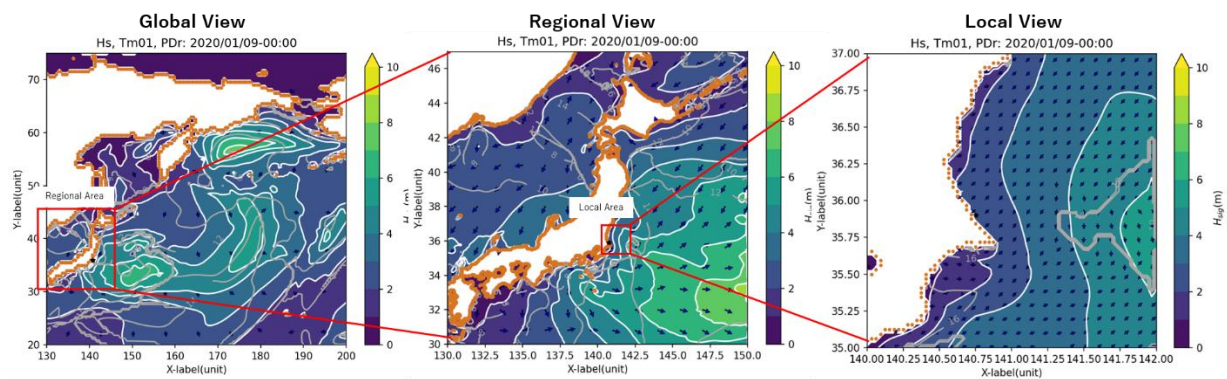


Figure 5- 4 Comparison of simulated significant wave height in the Global, Regional, and Local Models on 9 January 2020.

In contrast, the difference between the Regional and Local Models is relatively small. Both models produce similar spatial patterns of H_{sig} around the study area, suggesting that

the additional refinement from the Regional to the Local Model has only a limited effect on the overall wave-height distribution for this event. This result indicates that the major change in Hsig occurs between the Global and Regional scales, while further refinement to the Local Model mainly provides a more detailed spatial representation without substantially changing the general wave-height pattern.

Table 5- 2 Comparison of model configuration and significant wave height characteristics among the Global, Regional, and Local Models

Aspect	Global Model	Regional Model	Local Model
Bathymetry used	GEBCO, model grid 1/2° (~50 km)	JTOPO30, model grid 1/16° (~6–7 km)	JTOPO30, model grid 1/32° (~3–4 km)
Wind forcing used	GSM (~50 km model-scale forcing)	MSM (~5–7 km)	MSM (~5–7 km)
Spectral wave boundary condition	No external spectral boundary; forced by GSM wind	Spectral wave boundary from the Global Model + MSM wind forcing	Spectral wave boundary from the Regional Model + MSM wind forcing
Result of Significant Wave Height (Hsig)	Generally underestimates Hsig near the study area and does not reproduce the peak as well	Produces higher Hsig than the Global Model and shows a similar spatial distribution to the Local Model.	Shows a spatial distribution similar to the Regional Model, indicating limited additional change from Regional to Local resolution

5.3 Results of Local and Detail Model Comparison

5.3.1 Comparison of Local and Detail Model Bathymetry

To investigate whether finer spatial resolution can improve the representation of local wave conditions, the Local Model was further nested into three higher-resolution Detail Models. The Local Model uses JTOPO30 bathymetry with an original resolution of 30 arc-seconds, approximately 900 m, and a model grid resolution of 1/32°. For the Detail Models, higher-resolution bathymetric data obtained from topographic survey data were used. Detail Model 1 has a spatial resolution of 1/128° and receives its spectral wave boundary condition from the Local Model. Detail Model 2 further increases the resolution to 1/512° and uses the output from Detail Model 1 as its boundary condition. Finally, Detail Model 3 uses the finest resolution of 1/2048°, with its boundary condition obtained from Detail Model 2.

As shown in Figure 5.5, the bathymetric representation in the Detail Models reaches the hundred-meter scale, allowing smaller micro-topographic features of the seabed and coastline to be represented more clearly. These fine-scale features are not captured as distinctly in the coarser Local Model and can influence local wave propagation through diffraction, resulting in greater variation in wave direction and directional characteristics.

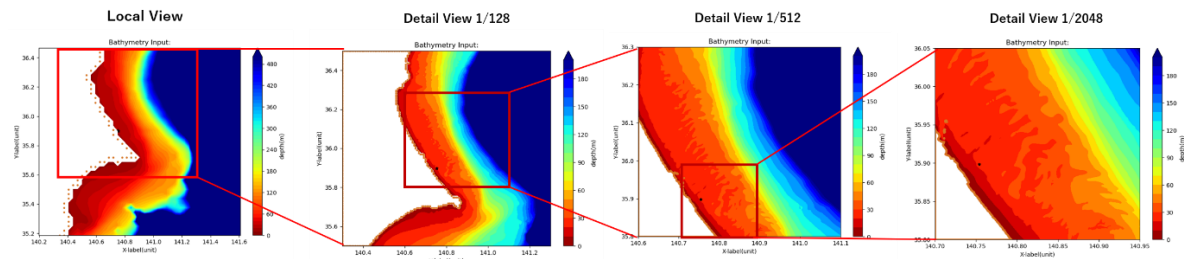


Figure 5- 5 Bathymetric refinement from the Local Model to the high-resolution Detail Models.

5.3.2 Results of Directional Wave Spectrum

At the early stage of the storm event, as shown in Figure 5.6, two main incoming wave directions can be identified, approximately around 50° and 325° . In the Local Model, the energy contributions from these two directions are relatively comparable. As the spatial resolution becomes finer, the contribution from around 325° becomes more pronounced, while the contribution from around 50° becomes weaker. This change is more clearly represented in the higher-resolution Detail Models. The result suggests that the finer bathymetric representation affects the directional distribution of wave energy near the observation point. The smaller-scale bathymetric features captured in the Detail Models may influence local wave propagation through diffraction, which can modify the relative contribution of waves arriving from different directions.

At the peak stage of the storm event, as shown in Figure 5.7, the Local Model and Detail Model 1 show relatively similar incoming wave directions, approximately around 45° . However, with increasing spatial resolution, a slight shift in the dominant wave direction can be observed. Detail Model 2 shows a dominant direction of approximately $55\text{--}60^\circ$, while the higher-resolution models also show changes in the shape and distribution of the directional spectrum around the observation point. This indicates that wave direction is sensitive to the representation of finer bathymetric features, particularly under stronger wave conditions during the peak stage of the storm.

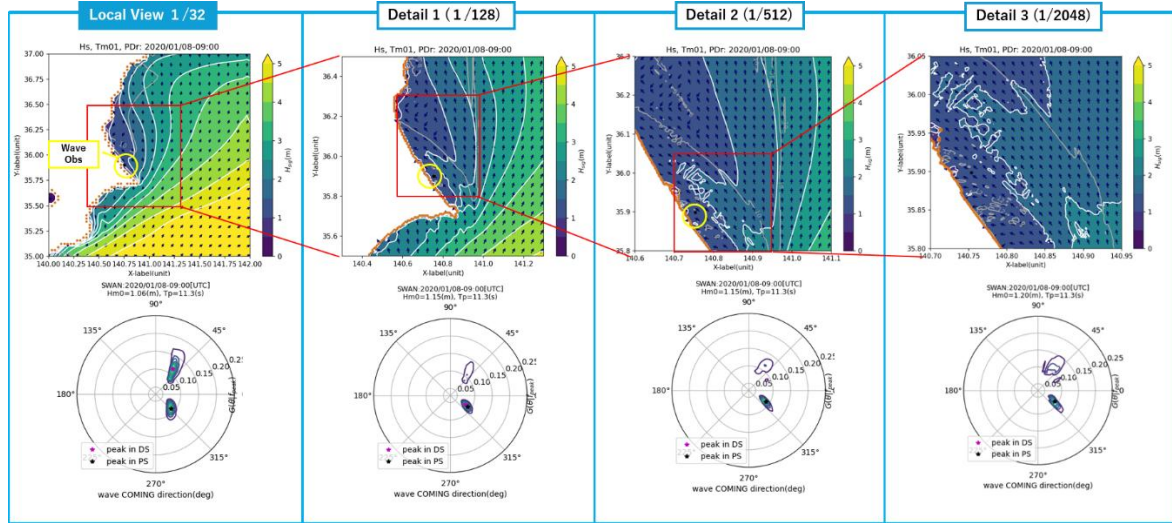


Figure 5- 6 Comparison of significant wave height and directional wave spectrum among different model resolutions at 09:00 on 8 January 2020.

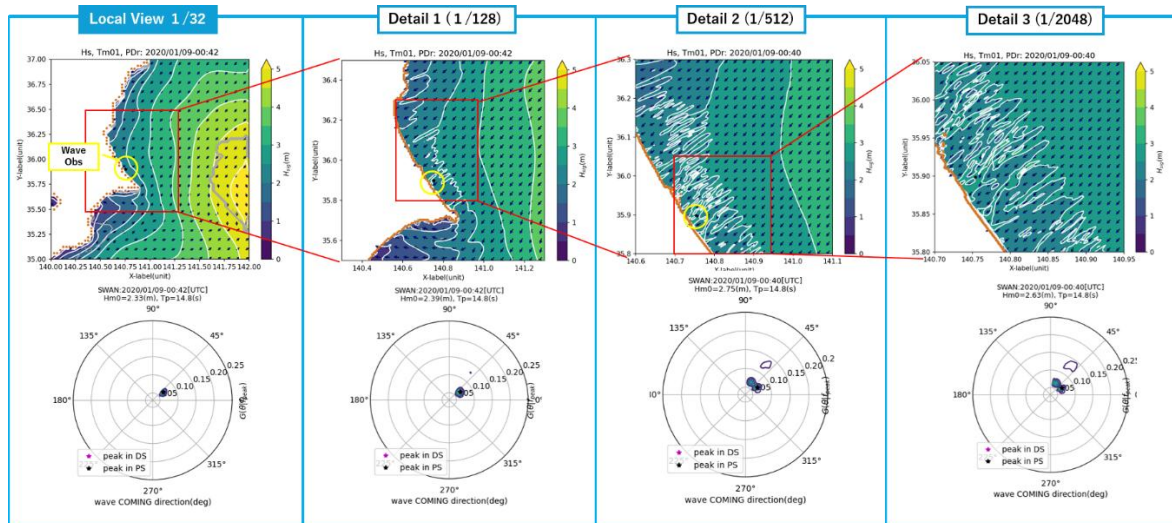


Figure 5- 7 Comparison of significant wave height and directional wave spectrum among different model resolutions at 00:42 on 9 January 2020.s

5.3.3 Results of Frequency Spectrum

The Frequency Spectrum (FSPR) was analyzed to evaluate how increasing spatial resolution influences the distribution of wave energy across different frequencies. The comparison was conducted between the Local Model and the higher-resolution Detail Models at two representative stages of the storm event: the initial stage on 8 January 2020

and the peak stage on 9 January 2020. Although the overall shape of the Frequency Spectrum remains generally similar among the different model resolutions, several differences can be observed in the magnitude and width of the spectral energy distribution.

During the initial stage of the storm event, as shown in Figure 5.8, the Detail Models exhibit slightly higher spectral energy density compared with the Local Model. The higher-resolution models also show a somewhat wider distribution of energy across the frequency range. Consequently, the integrated spectral energy area becomes larger as the model resolution increases. Despite these differences, the main spectral shape and the location of the dominant frequency remain relatively similar among the model cases. This indicates that increasing spatial resolution does not significantly change the general frequency characteristics of the incoming wave system, but allows a greater amount of wave energy to be represented in the simulation. The wider Frequency Spectrum in the Detail Models may be related to the improved representation of local bathymetric features, which can influence wave transformation as the waves propagate toward the observation area.

A similar tendency is observed during the peak stage of the storm event, as shown in Figure 5.9. The Frequency Spectrum produced by the Detail Models maintains the same general pattern as that of the Local Model, while showing slightly higher spectral energy density and a wider frequency distribution. The difference becomes more noticeable around the dominant lower-frequency component, where the higher-resolution models represent greater wave energy. As a result, the integrated spectral energy area of the Detail Models is larger than that of the Local Model. This result is consistent with the higher Significant Wave Height (H_{sig}) obtained from the higher-resolution simulations during the peak of the event, since H_{sig} is related to the total energy contained within the wave spectrum.

The comparison between the initial and peak stages also shows that the influence of spatial resolution on the Frequency Spectrum is mainly related to the amount of represented wave energy rather than a major change in the overall spectral shape. The higher-resolution Detail Models preserve the general frequency characteristics produced by the Local Model while representing slightly greater and more widely distributed spectral energy. This suggests that the large-scale characteristics of the Frequency Spectrum are primarily maintained through the nested boundary conditions, whereas the finer spatial resolution and more detailed bathymetric representation may contribute to local modifications of the wave-energy distribution.

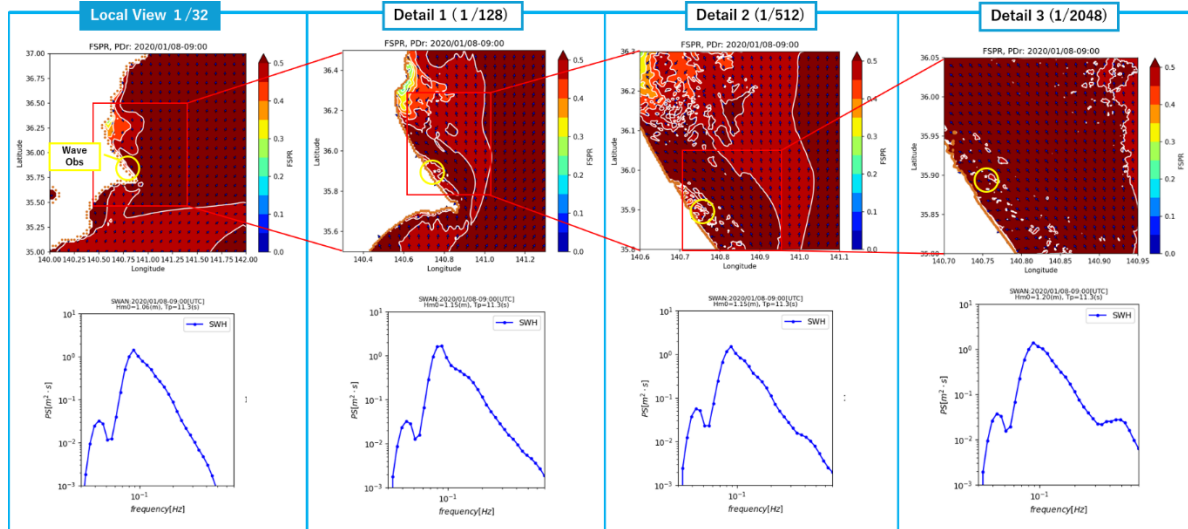


Figure 5- 8 Comparison of frequency spectrum among different model resolutions at 09:00 on 8 January 2020 during the early stage of the storm event.

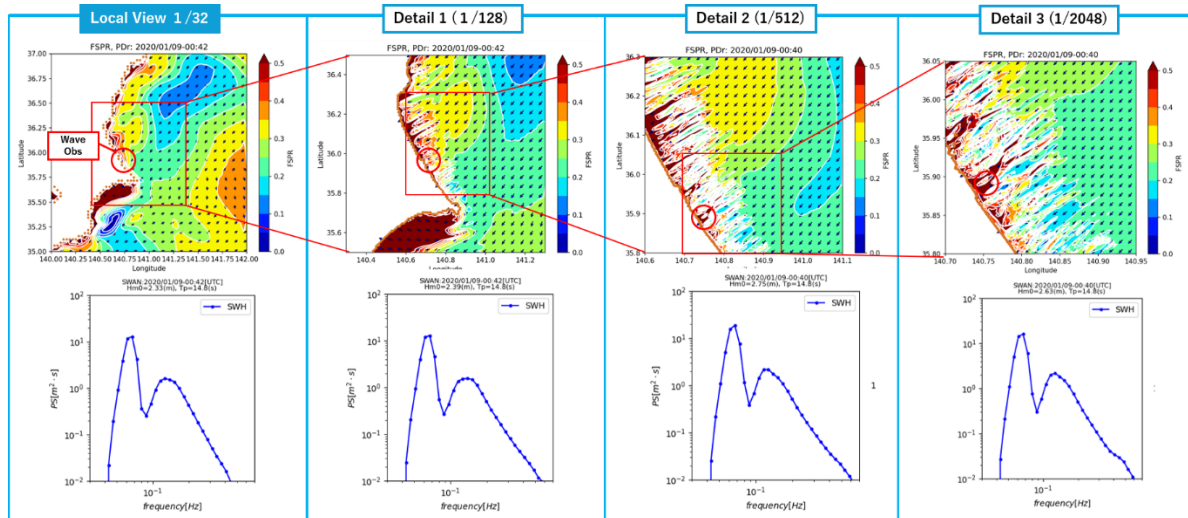


Figure 5- 9 Comparison of frequency spectrum among different model resolutions at 00:42 on 9 January 2020 during the peak stage of the storm event.

5.3.4 Results of Directional Spectrum

During the initial stage of the storm event, the Directional Spectrum (DSPR) shows clear differences among the model resolutions. As shown in Figure 5.10, the Local Model exhibits two relatively similar directional peaks, indicating that the wave energy is distributed between two main incoming directions. In Detail Model 1, these peaks become more distinct, with one direction showing a stronger concentration of energy. As the spatial resolution is further increased in Detail Models 2 and 3, the directional distribution becomes more complex, with additional variations in the peak structure and a wider range of wave directions. Although the general incoming wave characteristics are still maintained, the higher-resolution models are able to represent greater local directional variability.

During the peak stage of the storm event, as shown in Figure 5.11, the difference becomes more pronounced. The Local Model produces a relatively sharp Directional Spectrum, indicating that most of the wave energy is concentrated within a narrower directional range. In contrast, the Detail Models show a wider directional distribution, while Detail Models 2 and 3 exhibit more complex peak structures and changes in the dominant wave direction. As the grid size becomes smaller, the directional energy is less concentrated around a single peak and is distributed over a broader range of directions. This indicates that the Directional Spectrum becomes increasingly sensitive to spatial resolution, particularly during the stronger wave conditions of the peak storm event.

The changes in the Directional Spectrum are closely related to the improved representation of bathymetric features around the observation point. The Local Model uses relatively smooth and simplified bathymetry, whereas the higher-resolution Detail Models resolve increasingly detailed micro-topographic features of the seabed. At the finest resolutions, small-scale variations in seabed elevation and coastline geometry become clearly visible, allowing local wave transformation processes to be represented in greater detail. These micro-topographic features may modify the propagation path of incoming waves through diffraction and other local transformation processes, redistributing wave energy into different directions. As a result, the directional peaks become less concentrated and the directional distribution becomes wider and more complex as the spatial resolution increases.

This difference becomes especially important near the observation point, where the detailed seabed configuration can alter the incoming wave direction locally. In the coarser Local Model, these small bathymetric variations are smoothed and the wave energy remains concentrated within a narrower directional range. In the Detail Models, the same area is represented with much finer bathymetric information, allowing more directional variation to

appear in the simulation. This explains why the dominant peak changes and becomes less concentrated as the model resolution increases.

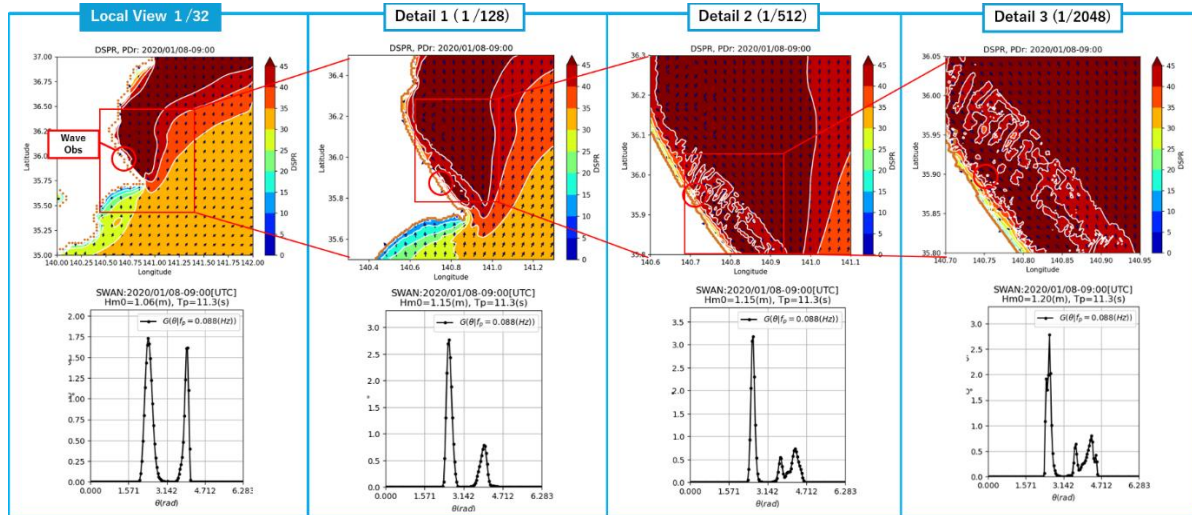


Figure 5- 10 Comparison of Directional Spectrum among different model resolutions at 09:00 on 8 January 2020 during the early stage of the storm event.

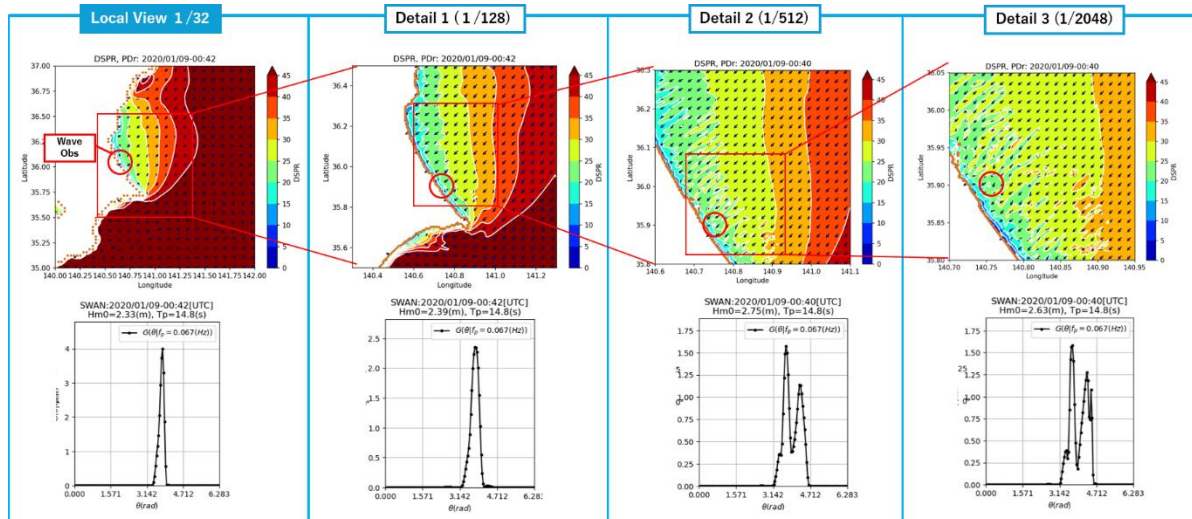


Figure 5- 11 Comparison of Directional Spectrum among different model resolutions at 00:42 on 9 January 2020 during the peak stage of the storm event.

5.4 Results of Wave Parameter Comparison

The simulated wave parameters were compared with the NOWPHAS observations to evaluate the effect of increasing spatial resolution on the wave hindcast results. Figure 5.12 presents the time-series comparison of Significant Wave Height (H_s), peak Wave Period (T_p), and Wave Direction (PDr) for the Local Model and the three Detail Models. The simulations generally reproduce the temporal development of the swell event observed by NOWPHAS, although differences remain in the magnitude and short-term variations of each parameter.

For Significant Wave Height (H_s), both the simulation and NOWPHAS observations show a clear increase during the swell event. The peak simulated wave height increases as the model resolution is refined from the Local Model to the Detail Models. At approximately 04:00 on 9 January 2020, the Local Model produces an H_s of 2.347 m, while Detail Model 1 increases to 2.467 m and Detail Model 2 reaches 2.753 m. The available result from Detail Model 3 gives a similar value of 2.751 m. This indicates that the improvement becomes smaller between Detail Models 2 and 3, even though the spatial resolution is further increased. The NOWPHAS observation reaches a higher peak of approximately 3.73 m at around 03:00, showing that all simulation cases still underestimate the observed maximum wave height. Nevertheless, the higher-resolution Detail Models provide a closer representation of the observed peak compared with the Local Model.

For peak Wave Period (T_p), the simulation cases show almost the same temporal variation regardless of spatial resolution. Both the numerical results and NOWPHAS observations show an increase in wave period as the swell event develops. Around the event, the observed T_p reaches approximately 17.1 s, while the simulation reaches approximately 19.5 s. Refining the model from the Local Model to the Detail Models does not substantially change the timing or general pattern of T_p . This suggests that the wave period is less sensitive to the local spatial resolution than the Significant Wave Height and is more strongly controlled by the characteristics of the large-scale incoming swell transferred through the nested model boundaries.

A different response can be seen for Wave Direction (PDr). NOWPHAS shows considerable short-term directional variability, including several rapid fluctuations during the storm event, whereas the simulated results generally show smoother directional changes. Differences among the Local and Detail Models become particularly visible during the highlighted periods around 09:00 on 8 January and 00:42 on 9 January. As the spatial resolution becomes finer, the Detail Models produce changes in the dominant wave direction compared with the Local Model.

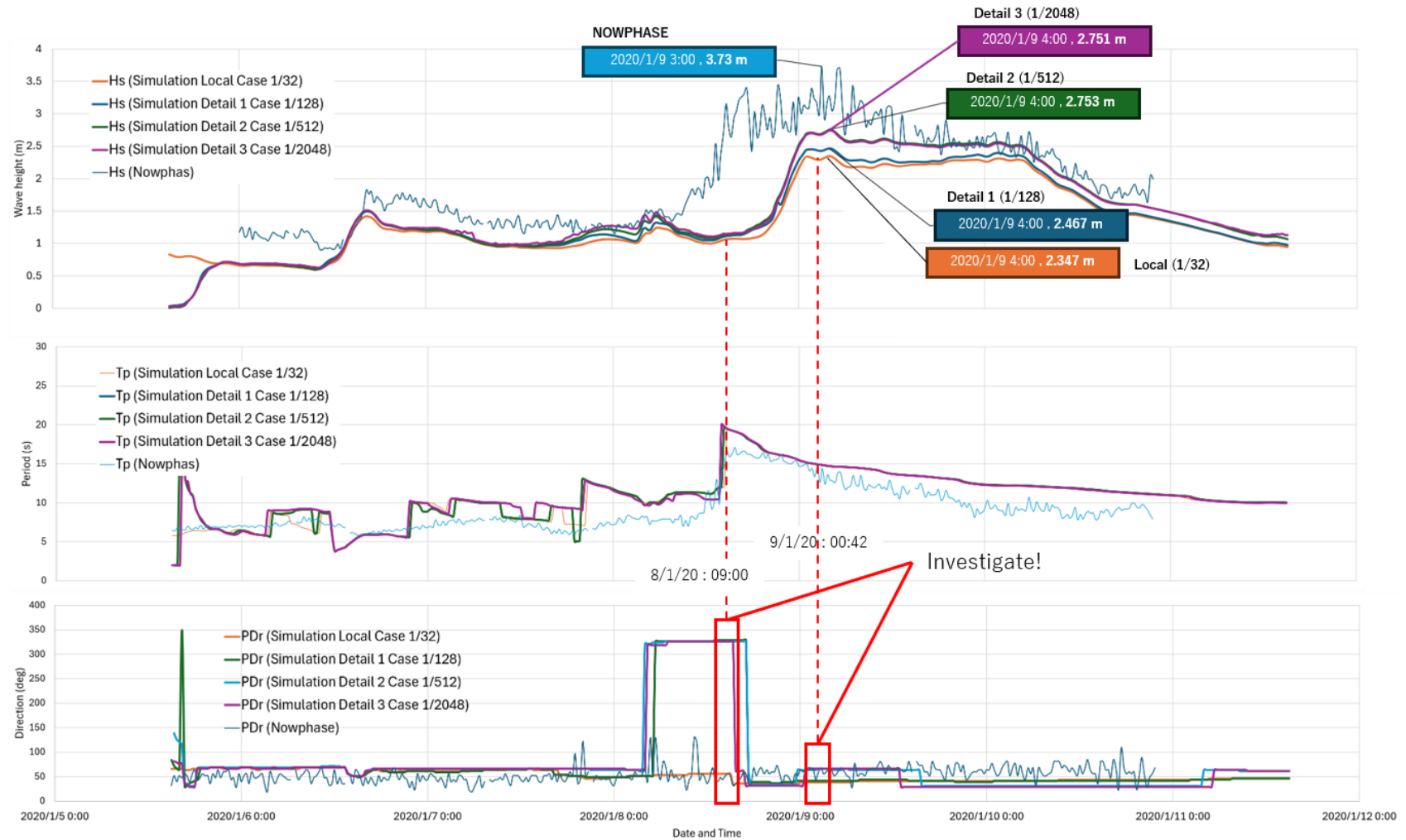


Figure 5- 12 Comparison of Significant Wave Height (Hs), peak Wave Period (Tp), and Wave Direction (PDr) between the Local and Detail Models and NOWPHAS observations during the winter storm event.

5.5 Results of Storm Distance Prediction

The propagation distance of the storm-generated swell was estimated using the relationship between wave period and arrival time. During swell propagation, longer-period wave components travel faster than shorter-period components and therefore arrive at the observation point earlier. This produces a decreasing trend in wave period with time, which can be used to estimate the distance between the wave source and the observation point. The swell-source distance was estimated using Equation (5.1).

$$d = \frac{g\Delta t}{4\pi(f_2 - f_1)} \quad (\text{e.q 5.1})$$

where:

d = estimated distance from the wave source (m)

g = gravitational acceleration (9.81 m /s²)

Δt = arrival – time difference between two wave – frequency components (s)

f₁ = frequency of the first wave component (Hz)

f₂ = frequency of the second wave component (Hz)

π = mathematical constant (3.14159)

The period gradient obtained from the simulation and NOWPHAS observation shows a similar decreasing tendency from 8 to 9 January 2020, as shown in Figure 5.13. The simulation period decreases from approximately 17.783 s to 11.865 s between 15:00 on 8 January and 23:21 on 9 January, while the NOWPHAS period decreases from approximately 16.638 s to 9.308 s during the same period. The linear regression shows a strong decreasing relationship for both datasets, with values of 0.8986 for the simulation and 0.9225 for NOWPHAS. This trend represents the dispersion characteristics of the incoming swell, in which longer-period components arrive earlier than shorter-period components.

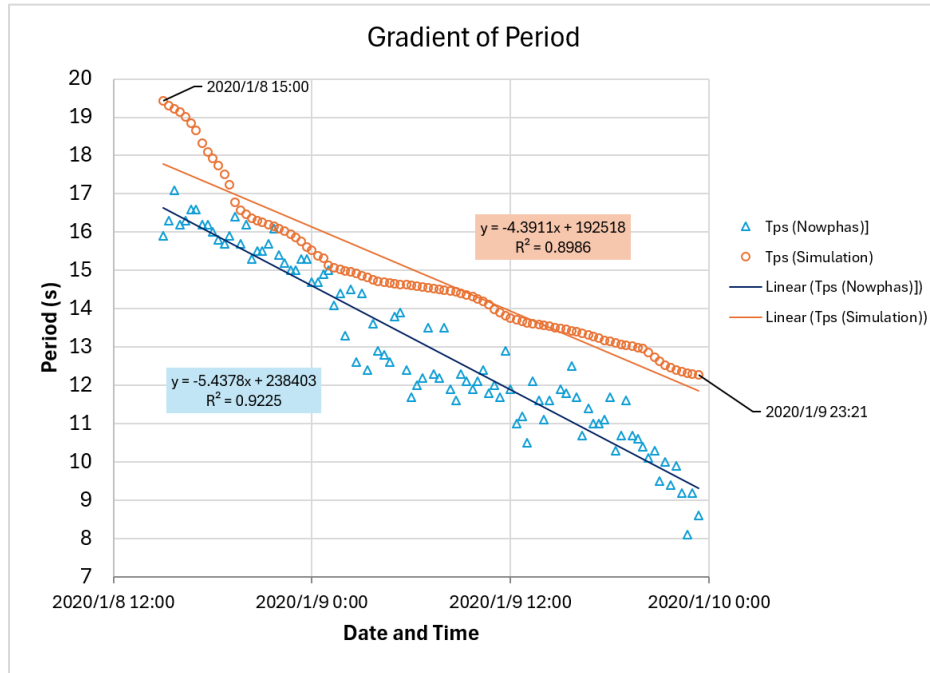


Figure 5- 13 Comparison of wave-period gradients between the simulation and NOWPHAS observation.

Table 5- 3 Estimated swell-source distance and average wave direction based on the simulation results.

No	Date	Δt (s)	T (s)	f (hz)	D (km)	Ave Dir (°)
1	2020/1/8 15:00	116,460	17.783	0.056	3241	39.5
2	2020/1/9 23:21		11.865	0.084		

Table 5- 4 Estimated swell-source distance and average wave direction based on the NOWPHAS observations.

No	Date	Δt (s)	T (s)	f (hz)	D (km)	Ave Dir (°)
1	2020/1/8 15:00	116,460	16.638	0.060	1921	58.11
2	2020/1/9 23:21		9.308	0.107		

Based on the values summarized in Tables 5.3 and 5.4, the simulation gives an estimated swell-source distance of approximately 3,241 km with an average incoming wave direction of 39.5°, whereas the NOWPHAS observation gives a shorter estimated distance of approximately 1,921 km with an average direction of 58.11°. Although both datasets show a similar decreasing period trend, the relatively small difference in the period gradient results in a considerable difference in the estimated propagation distance. This indicates that the storm-distance estimation is highly sensitive to the selected wave periods and their arrival-time difference. The calculated storm-source distance should be interpreted as an approximate estimate rather than an exact location.

6 Conclusions

- The higher-resolution model shows better capability to capture the peak Significant Wave Height (Hsig) value during the storm event compared with the coarser local model, indicating improved accuracy in representing extreme wave conditions.
- The influence of higher resolution model on wave period (Tp) is limited. All model cases show similar temporal variations, suggesting that Tp is mainly controlled by the large-scale wave system rather than spatial resolution.
- The Directional Spectrum is sensitive to spatial resolution. The Detail Model captures larger variations in wave direction, which are likely caused by the better representation of bathymetric around the observation point. These small-scale topographic variations can modify wave propagation through diffraction, leading to a more diverse directional distribution.
- Frequency Spectrum shows similar patterns among different model resolutions. However, the Detail Model exhibits a slightly wider spectrum with a larger integrated energy area. Although the spectral shape remains similar, the increased energy representation allows the model to better capture peak wave conditions, which may contribute to improved accuracy in Significant Wave Height (Hsig) estimation.
- Directional Wave Spectrum changes by increasing model resolution with the differences in Directional Spectrum and Frequency Spectrum

Influence of Spatial Resolution	Hsig	Tp	Frequency Spectrum	Directional Spectrum
	Yes	Negligible	Yes	Yes

The storm-distance prediction indicates that both the simulation and NOWPHAS observations reproduce the dispersive behavior of the swell; however, the estimated source distances differ considerably, at approximately 3,241 km from the simulation and 1,921 km from NOWPHAS. This difference shows that even a small change in the wave-

period gradient can strongly affect the estimated propagation distance, so the predicted storm-source location should be interpreted as an approximate indication rather than an exact position.

7 My opinion/comments/impressions/suggestions after GRI

Throughout my internship at the Port and Airport Research Institute (PARI), I focused on studying numerical wave modeling using a spectral wave model. The main objective of this training was to deepen my understanding of how numerical wave models reproduce wave generation and propagation from large-scale offshore areas toward coastal regions. During the internship, I developed several computational domains, including global, regional, local, and detailed models, and learned how different spatial resolutions and model configurations influence the simulated wave conditions. Python scripts were also used to visualize and analyze the simulation results.

In addition to model development, I studied the theoretical background and computational procedures of the spectral wave model in greater detail. I learned about the governing equations, model configuration, boundary conditions, and numerical calculation procedures. I was also introduced to parallel computing methods, which are particularly important for performing simulations with higher spatial resolution and larger computational domains. Through these activities, I gained a better understanding not only of how to operate the model but also of how the numerical model works internally.

The simulation results were compared with observed wave data to evaluate the model performance. One of the main discussions focused on the difference between simulated and observed wave conditions during swell events. In particular, we examined the relationship between wave period and the distance of the storm system from the observation area. This analysis helped me understand how distant meteorological conditions can influence wave characteristics and how numerical results should be interpreted together with observational data.

The training at PARI was extremely valuable for my academic and professional development. Through discussions with researchers in the wave group, I gained practical knowledge about numerical wave modeling and learned how researchers approach real coastal engineering problems. I also realized the importance of carefully examining numerical results rather than simply operating the model. Understanding the physical processes, numerical assumptions, and limitations of the model is essential for producing reliable simulations.

I am sincerely grateful to Dr. Fujiki and all members of the wave group for their guidance and support throughout the internship. Their explanations and discussions helped me broaden my understanding of wave modeling and coastal engineering research. The experience also provided me with valuable insight into the research environment at PARI and the way numerical modeling is applied to practical engineering problems.

For future training programs, I believe it would be beneficial to include more detailed discussions on the theoretical equations, numerical algorithms, and source codes used in the model. Additional opportunities to compare numerical simulations with field observations or experimental results would also strengthen the understanding of wave processes. As a PhD student, I am particularly interested in studying not only how to use numerical models but also how the equations are solved computationally and how the computational performance can be improved through methods such as parallel computing.

I also had a very enjoyable experience during the internship. The welcome and farewell parties gave me opportunities to interact more closely. These activities helped us build stronger bonds and made me feel more comfortable and welcomed during my stay at PARI. Because of this friendly environment, I was able to enjoy both the research activities and my daily life throughout the internship.

8 Reference of this research

Note: (The version submitted to PARI included previous studies and some theoretical algorithms for numerical simulation, which are not mentioned in this report. Detailed literature citations are not shown here.)

9 Signature of supervisor

Signature of supervisor		
	Approval Seal (GRI Advisor)	