Cyclone Lahar and the Associated Wave Characteristics: A Numerical Modelling Approach

Hui Xi[†‡*], Yang Lu[†‡], and Zizhan Zhang[†‡]

[†] State Key Laboratory of Geodesy and Earth's Dynamic
Institute of Geodesy and Geophysics, Chinese Academy of Sciences
Wuhan 430077, China
[*] xihui@asch.whigg.ac.cn

[‡] University of Chinese Academy of Sciences
Beijing 100049, China

LRH: Xi, Lu, and Zhang

RRH: Numerical Modelling of Cyclone Lahar

Date manuscript received: 4 April 2019

Date manuscript accepted after revision: 26 June 2019

ABSTRACT

Natural hazards, especially tropical cyclones, are persistent visitors of Bay of Bengal which results in significant loss of life, damage to infrastructure, marine life, and biodiversity. This paper discusses the development of a cyclone model for the Bay of Bengal and adjoining the Andaman Sea, especially to understand the wave characteristics during cyclones of the Andaman Islands, and simulated the nearshore spectral wave characteristics of South Andaman during the Cyclone Lahar, which hit the Islands from 23rd November 2013 to 26th November 2013. The spectral wave model of MIKE 21 developed by Danish Hydraulic Institute was used to simulate the wave characteristics of Bay Bengal and the Andaman Sea; whereas, the observed wave characteristics of a Wave Rider Buoy located at Port Blair, Andaman, was used for the validation of the model. A maximum simulated significant wave height of approximately 18 m was observed from the model of the cyclone and maximum simulated significant wave heights around 3.5 m were observed on the nearshore coastal waters of Port Blair, Andaman Islands.

ADDITIONAL INDEX WORDS: *Nearshore wave characteristics, significant waves heights, Bay of Bengal.*

INTRODUCTION

Tropical cyclones which are mostly associated with warm and moist air and due to this reason they originate only over warm ocean waters near the equator. The favourable conditions required for the formation of cyclones are: (a) Warm sea surface temperature, (b) Large convective instability, (c) Low-level positive vorticity, (d) Weak vertical wind shear of horizontal wind, and (e) Adequate Coriolis force (Sarker, 2018). The development of cyclonic storms is a frequent phenomenon in the Bay of Bengal, and it accounts for about 7% of the global annual total number of cyclones (Dube *et al*., 2004). The genesis of a cyclone is a regular feature in the pre-monsoon and (May) and post-monsoon (October to November) over Bay of Bengal (Patra, Mohanty, and Mishra, 2015). Timely prediction of these storms can reduce the loss of human life and damage to infrastructure. Nateshan *et al*. (2013) have estimated the wave heights during cyclones Baaz, Fanoos, and 7B in the Bay of Bengal. Patra *et al*. (2015) developed a wave model to estimate and validate offshore wave characteristics of cyclones occurred in the Bay of Bengal from 2008 to 2009. Aboobacker *et al*. (2009) estimated the spatial characteristics of the nearshore waves of Paradeep, India during monsoons and extreme events.

This paper is concentrated on the cyclone Lahar for illustrating the application of numerical modelling tools to simulate the waves generated by cyclones and to assess the nearshore wave characteristics due to the cyclone on the coastal waters of Andaman and Nicobar Islands.

The cyclone Lahar which originated in the Bay of Bengal from 23rd to 28th November 2013 is categorized as a very severe cyclonic storm. It formed as depression over the Andaman Sea on 23rd November 2013 evening and intensified into cyclonic storm Lahar on 24th November 2013 near latitude 10.0°N and longitude 95.0°E. The salient feature of this particular cyclone was that it was the first severe cyclone storm to cross Andaman and Nicobar Islands after 1989. This cyclonic system crossed Andaman and Nicobar Islands near Port Blair at 0000 UTC of 25th

November 2013 as a severe cyclonic storm. While moving west-northward direction over west central Bay of Bengal, this particular system weakened from 27th November afternoon and crossed Andhra Pradesh coast near to Machlipatanam around 8:30 UTC of 28th November 2018 as a deep depression i.e.it rapidly weakened over the sea from the stage of a very severe cyclonic storm to a depression in just 18 hours (IMD, 2014). The track of the cyclone is given in Table 1.

For the simulation of a cyclonic model, a large domain is required. The model covers the Bay of Bengal and its wider surroundings including Andaman and Nicobar Islands as the Lahar is the only cyclone that crossed the Islands after 1989. The MIKE 21 Spectral Wave Model developed by DHI (Danish Hydraulic Institute) is used in the present study to simulate the cyclone. The assessment of nearshore wave climate of South Andaman Islands during cyclonic winds was the prime objective of the model simulation.

METHODS

This part describes the generation of the model, initially wind and pressure fields of the Cyclone Lahar is generated. The generated fields were then incorporated into the regional model developed and finally the model was validated.

Wind and Pressure Field Generation

The cyclonic wind and pressure fields for the cyclone Lahar were generated by using MIKE 21 Cyclone Wind Generation tool. This tool generally computes the wind and pressure considerations due to cyclones by using different cyclonic parametric models such as Young and Sobey model, Holland-single vortex model, Holland-double vortex model and Rankine vortex model. The wind and pressure fields for the cyclone Lahar was generated by using Young and Sobey model. The cyclonic parameters used for the generation are: (a) Time, (b) Track of the cyclone, (c) The radius of the maximum wind speed, (d) Maximum wind speed, (e) Central pressure, and (f) Neutral pressure of the cyclonic system. The data required for the generation

wind and pressure field was obtained from the IMD best track results. Figures 1 and 2 show an example for wind and pressure fields of the cyclone Lahar on 23/11/2013 4:00 pm. These wind and pressure fields were used to drive the cyclonic wave model for the study.

Regional Model Setup of Bay of Bengal

A Regional model was setup for the study based on MIKE 21 Spectral Wave model giving special considerations for Andaman and Nicobar Islands by constructing finer mesh around the Islands. Various physical phenomena like wave growth by the action of wind, non-linear wave-wave interactions, dissipation due to white capping, dissipation due to bottom friction, dissipation due to depth-induced wave breaking, wave refraction, wave shoaling and wave current-interactions were considered during the model development. The fully spectral formulation used in the model was based on wave action conservation equation, where the directional-frequency wave action spectrum is the dependable variable.

This regional wave model covers the coastlines of India including the coastlines of Andaman and Nicobar Islands, Sri Lanka, Myanmar and Indonesia (Figure 3). This model was then used to simulate the generation and propagation of cyclone waves. An unstructured flexible mesh with variable cell sizes was used in the model. The bathymetry required for the model was taken from MIKE C-Map Global Database.

Numerical Modelling of Waves for the Cyclone Lahar

The regional wave model which was set up for the present study was based on the MIKE 21 Spectral Wave model (SW), and this particular model was employed in simulating the growth and propagation of the cyclonic waves. For this model, the fully spectral formulation with in-stationary time formulation was used. Low order numerical scheme was employed in the model. Wave diffraction, wave breaking, bottom friction and white capping were also included in the simulation of the model. With the JONSWAP fetch growth empirical formulations, the quadruplet wave interaction were also included.

The wave model for this study was driven by the wind speed and pressure field simulated, as shown in Figure 1 and 2. The entire passage of the cyclone Lahar was covered until its landfall.

Validation of the Model

The simulated maximum significant wave heights were compared against the maximum significant wave heights recorded by the Rider Buoy of NIOT at Port Blair (92.765°E, 11.661° N). The simulated significant wave heights from the model are in good agreement with the observed data hence proving a robust validation of the model.

RESULTS

The cyclone Lahar model shows that a maximum significant wave height around 18.0 m has occurred at a location of 88.243898°E, 14.718843°N on 26th November 2013 22:00:00 hours. The two-dimensional distribution of wave heights is shown in Figure 4 for this particular time step. Figure 4 indicates that the maximum wave heights were generated near the western coast of Andhra Pradesh. The timely distribution of significant wave heights at this location is shown in Figure 5 and indicates that maximum significant wave heights higher than 10 m were sustained approximately more than 28 hours and wave heights more than 16 m sustained approximately around 12-14 hours.

Further analysis was done on the wave characteristics due to the cyclone Lahar on the nearshore coastal waters of Andaman and Nicobar Islands. The model shows a maximum significant wave height of 3.7 m has occurred at 92.753346°E, 11.642340°N (Carbyn's Cove Beach, Port Blair) on 25th November 2013 00:00:00 hours. A two-dimensional distribution of wave heights are shown in Figure 6. The temporal distribution of significant wave heights at this location is shown in Figure 7. The figure specifies that significant wave heights more than 3m sustained for approximately 5 hours.

DISCUSSION

The model results indicate that the Cyclone Lahar was a significant event which generated waves up to 18 m at the height of the storm. The cyclone moved west-northwestwards over the central Bay of Bengal. A better understanding of wave characteristics due to the Cyclone Lahar on the near shore of Andaman and Nicobar Islands were achieved from this particular study and which is very important for these Islands that are vulnerable to natural disasters like tsunamis and cyclones. Numerical modelling techniques can be used as a better tool for making enhanced strategies for Disaster Risk Reduction and management specifically in the era of changing climate.

CONCLUSIONS

The study underlines how numerical how a robust wave model can be utilized to simulate offshore and nearshore wave characteristics and impacts of cyclones over coastal developments and infrastructures. The methodology used in this for modelling cyclones in the Bay of Bengal and Andaman Sea could be applied to other sites around the world that are affected by these extreme events.

ACKNOWLEDGEMENTS

The authors would like to thank Pondicherry University for the funding & lab facilities and DHI, India for providing with all the necessary technical support.

LITERATURE CITED

Aboobacker, V.M.; Vethamony, P.; Sudheesh, K., and Rupali, S.P., 2009. Spectral characteristics of the nearshore waves off Paradip, India during monsoon and extreme events. *Natural Hazards*, 49(2), 311-323.

Dube, S.K.; Chittibabu, P.; Sinha, P.C.; Rao, A.D., and Murty, T. S., 2004. Numerical modelling of storm surge in the Head Bay of Bengal using location specific model. *Natural Hazards*, 31(2), 437-453.

India Meteorological Department, 2014. *A Preliminary Report on Very Severe Cyclonic Storm 'LEHAR' over the Bay of Bengal*. Cyclone Warning Division, New Delhi, 27p.

Natesan, U.; Rajalakshmi, P.R.; Ramana Murthy, M.V., and Ferrer, V.A., 2013. Estimation of wave heights during cyclonic conditions using wave propagation model. *Natural Hazards*, 69(3), 1751–1766.

Patra, S.K.; Mohanty, P.K.; Mishra, P., and Pradhan, U.K., 2015. Estimation and validation of offshore wave characteristics of Bay of Bengal cyclones (2008-2009). *Aquatic Procedia*, 4 (2015), 1522-1528.

Sarker, M.A., 2018. Numerical Modelling of Waves from the 1991 Cyclone in the Bay of Bengal (Bangladesh). *American Journal of Water Science and Engineering*, 4(3), 66-74.

FIGURES

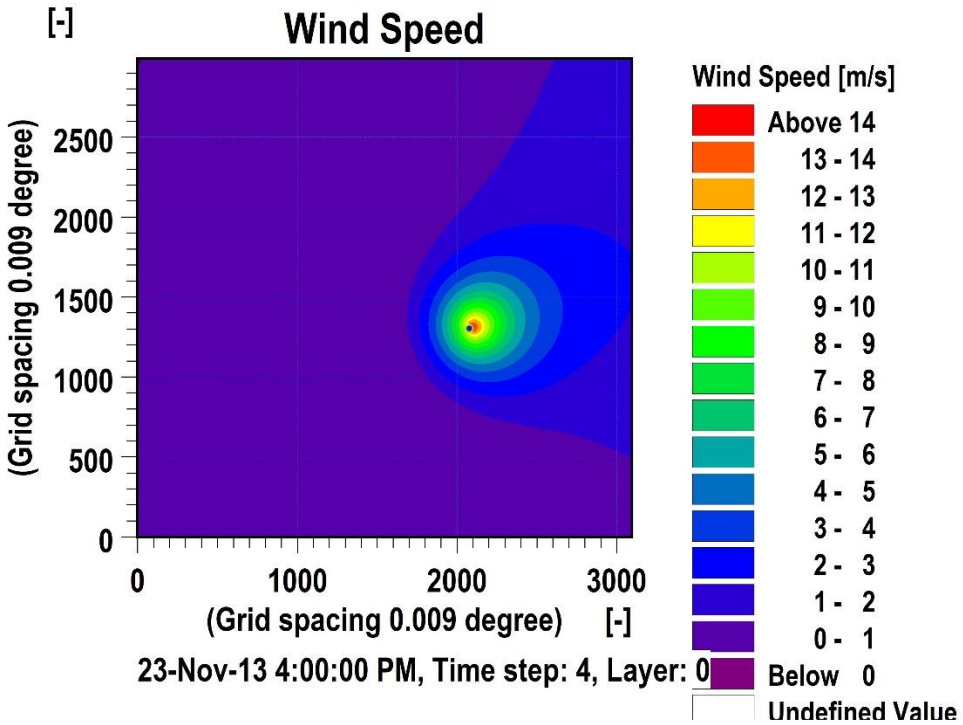

Figure 1. Wind fields of the Cyclone Lahar.

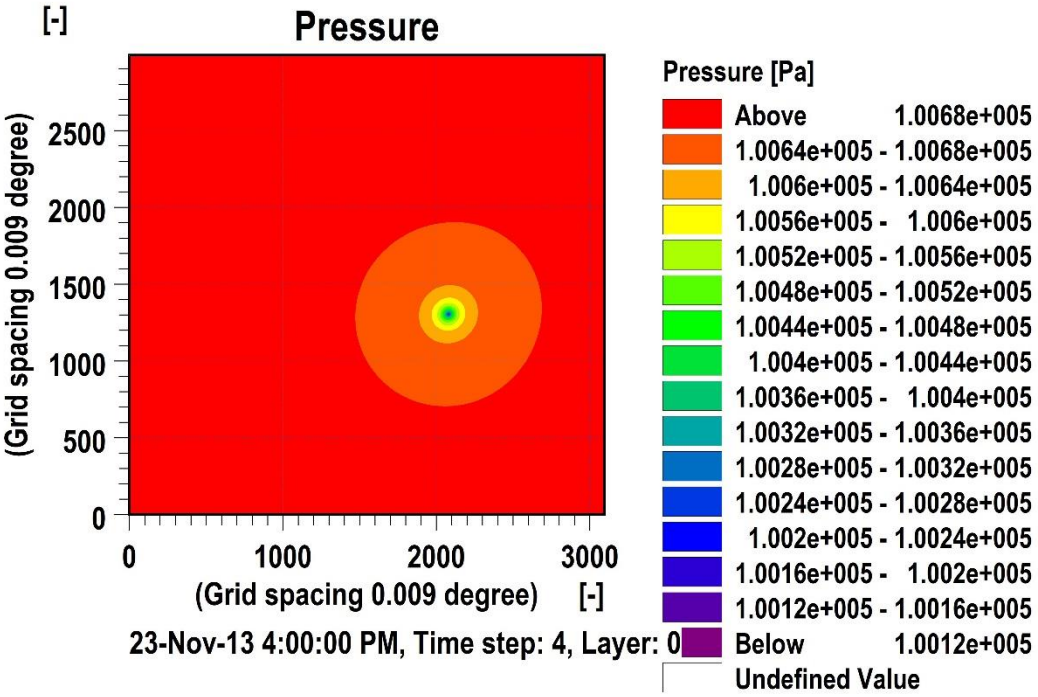

Figure 2. Pressure fields of the Cyclone Lahar.

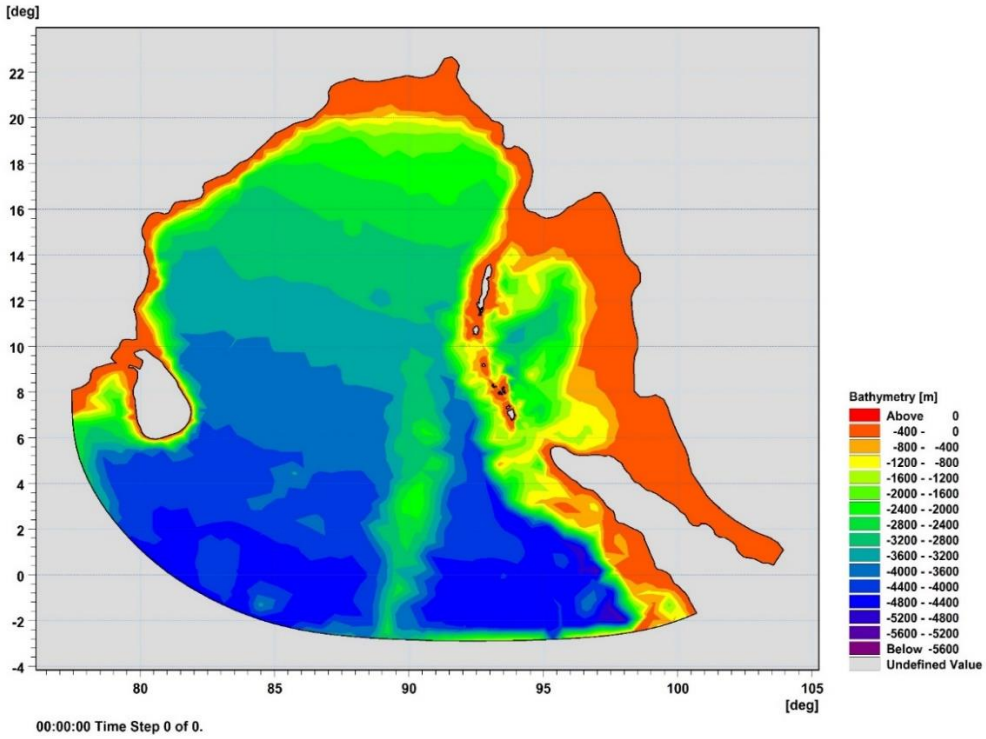

Figure 3. Regional wave model extent and bathymetry.

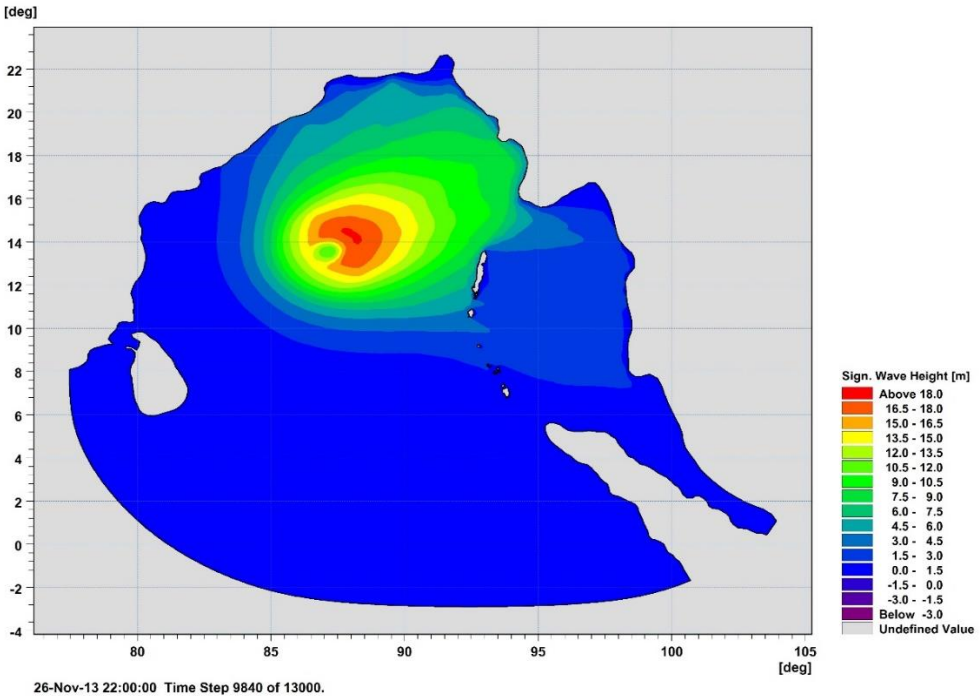

Figure 4. Two Dimensional distribution of significant wave heights of Cyclone Lahar on 26-November-2013 22:00:00 hours.

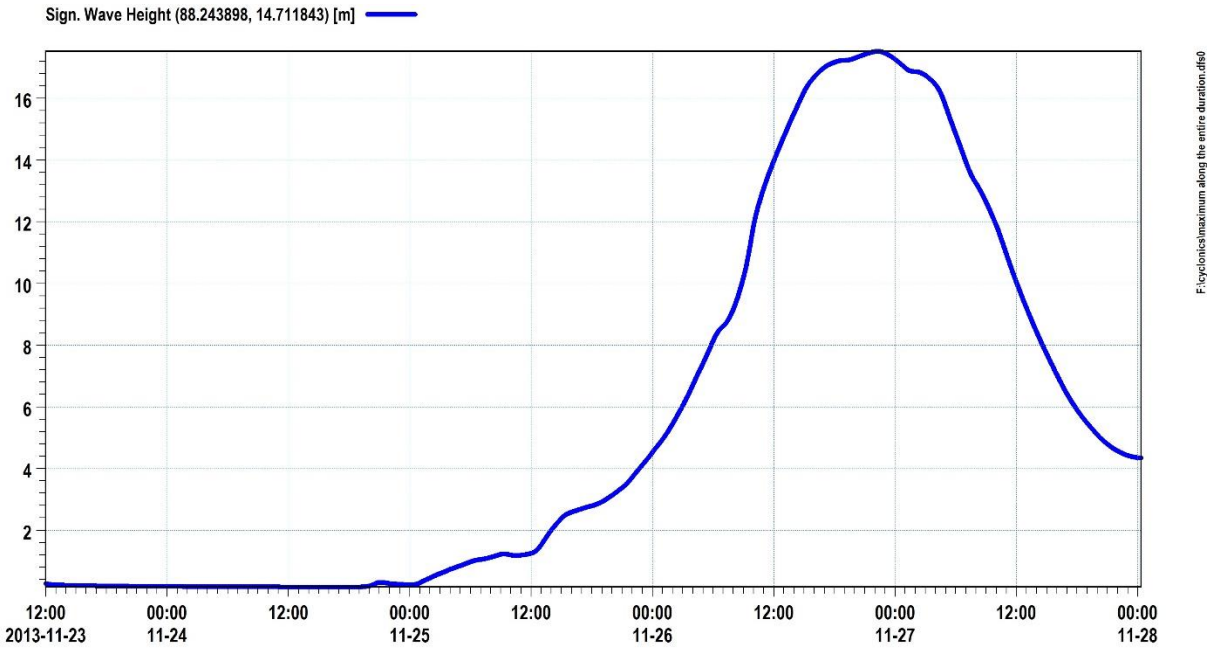

Figure 5. Time series distribution of significant wave heights at 88.243898°E, 14.718843°N.

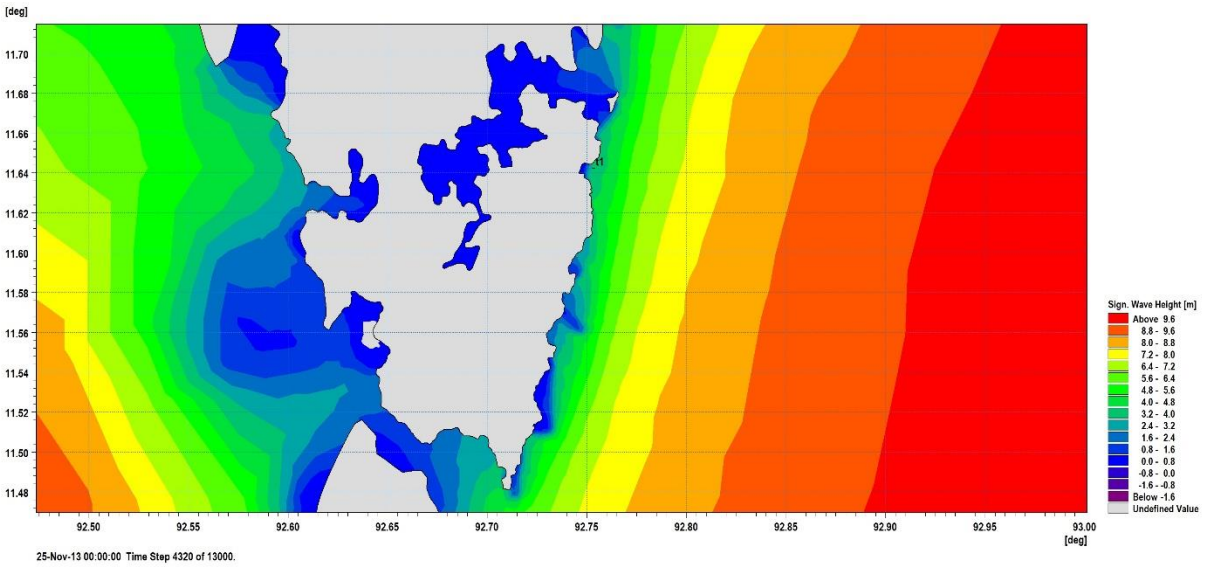

Figure 6. Significant wave heights of Cyclone Lahar on 25-November-2013 on the nearshore coastal waters of Port Blair (92.753346 E, 11.642340 N, Carbyn Cove Beach).

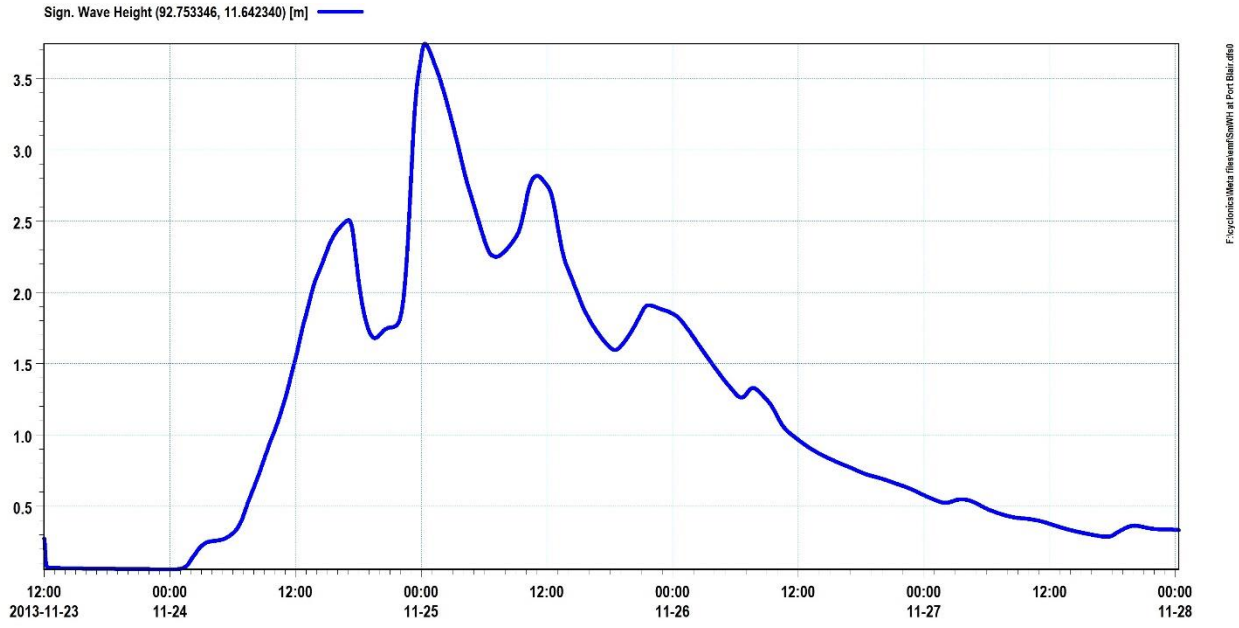

Figure 7. Time series distribution of significant wave heights at 92.753346 E, 11.642340 N, Carbyn Cove Beach.

Date	Time UTC	Longitude (°E)	Latitude (°N)	Radius of the Maximum Winds (Km)	Maximum 1-hourly wind speeds (m/s)	Central Pressure (hPa)	Constant neutral pressure (hPa)
23-11-13	0	96.5	8.5	25	13.61	1004	1007
23-11-13	6	96	9	30	16.33	1002	1007
24-11-13	12	95	10	35	19.06	999	1006
24-11-13	15	95	10	40	21.78	998	1006
24-11-13	18	94.5	10.5	45	21.78	998	1006
24-11-13	21	94	10.7	45	24.5	996	1006
24-11-13	24	93.5	11	45	24.5	996	1006
24-11-13	27	93.5	11	45	24.5	996	1006
24-11-13	30	93	11.5	55	24.5	996	1006
24-11-13	33	92.5	11.5	55	24.5	996	1008
24-11-13	36	92.5	12	60	29.94	992	1007
25-11-13	42	91.5	12	60	29.94	988	1005
25-11-13	45	91.5	12	60	32.67	988	1005
25-11-13	48	91.5	12.5	55	32.67	988	1005
25-11-13	51	91	12.5	65	32.67	988	1005
25-11-13	54	91	12.5	70	29.94	988	1005
25-11-13	57	91	12.5	70	35.39	984	1006
25-11-13	60	90.5	12.5	70	38.11	982	1006
26-11-13	63	90	12.5	70	38.11	982	1006
26-11-13	66	89.5	12.5	70	38.11	982	1006
26-11-13	69	89	13	70	38.11	982	1006
26-11-13	72	88.5	13	75	38.11	982	1006
26-11-13	75	88	13.1	75	40.8	980	1006
26-11-13	78	87.5	13.2	75	40.8	980	1006
26-11-13	82	87	13.5	75	40.8	980	1006
26-11-13	85	86.5	13.5	70	40.8	980	1006
27-11-13	88	86	14	65	38.11	982	1006
27-11-13	91	85.5	14	55	35.36	984	1006
27-11-13	94	85	14.5	55	29.92	988	1005
27-11-13	97	84.5	14.5	45	29.92	988	1005
27-11-13	100	84	14	50	24.3	996	1006
27-11-13	103	83.5	15	30	21.76	998	1006
27-11-13	106	82	15.5	30	16.32	1000	1005
27-11-13	109	81.7	15.7	30	16.32	1000	1005
28-11-13	112	81.3	15.7	25	16.32	1000	1005

Table 1. ***Track and data of Cyclone Lahar.***

【其他要求说明】（投稿时，此部分需删除）

The manuscript text in a WORD document, double spaced.

Each figure should be submitted as a separate image file (.jpg or .tif) with at least 300 ppi resolution.

All tables submitted in a separate WORD document (if the paper has tables).