CHIN. PHYS. LETT. Vol. 32, No. 4 (2015) 044301

Preliminary Study on Underwater Ambient Noise Generated by Typhoons *

WANG Jing-Yan(王璟琰)[1,2], LI Feng-Hua(李风华)[1**]

[1] State Key Laboratory of Acoustics, Institute of Acoustics, Chinese Academy of Sciences, Beijing 100190
[2] University of Chinese Academy of Sciences, Beijing 100190

(Received 13 November 2014)

We present a typhoon-generated noise model with which the noise intensity during typhoons can be estimated accurately. The model is verified through experimental study, and the simulation results agree reasonably with the experimental data. The measured noise intensity is approximately proportional to the cube of the local wind speed.

PACS: 43.30.Nb, 43.30.Pc, 43.50.Rq characteristics DOI: 10.1088/0256-307X/32/4/044301

Accurate estimation of typhoon intensity is critical for typhoon classification.[1] Here we show that the passive ocean acoustic measurement from a single hydrophone deployed in water may provide a safe and inexpensive way to investigate typhoon intensity.

Sea-surface agitation driven by wind is a dominant source of ambient noise (from hundreds to thousands of hertz) in the ocean.[2] The noise intensity generated by a typhoon is considered to be the sum of the noise fields radiated from the wind-driven sources within the ocean area dominated by the typhoon.[3] Previous work[4–8] has shown that the noise intensity level (in dB) is linearly related to the logarithm of the wind speed. Some noise models are proposed by using the linear relationship between the noise intensity and the wind speed. These models work well if the wind speed is range-independent in the region. However, the models need reconsideration when the wind speed is range-dependent during a typhoon.

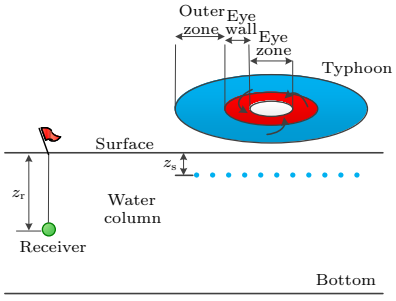

Fig. 1. The geometry of the noise model.

In this Letter, a theoretical derivation of the typhoon-generated noise intensity is proposed based on the normal mode theory. This model has a good performance in the range-dependent wind speed situation. The relationship of wind speed and experimental data is also investigated.

The geometry of the typhoon-generated noise problem is shown in Fig. 1. The wind-driven noise sources are modeled as monopoles spanning at a depth of a quarter wavelength, which act as dipoles due to the pressure-released sea surface. Noise intensity at the receiver is determined by integrating the sound radiated from all these sources, whose magnitudes depend on the local wind speed and frequency.

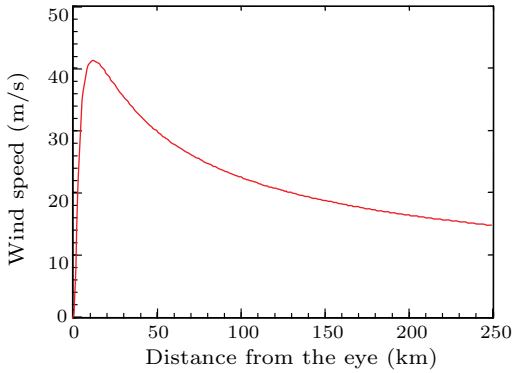

Fig. 2. The wind speed profile of a typhoon.

The empirical formula describing the relationship of the wind-driven noise intensity and wind speed is presented as[9]

$$SI(f, v) = C(f)v^n, \tag{1}$$

where SI is the source intensity, $C(f)$ is a frequency dependent term, and v is the local wind speed.

Typhoons can be characterized by surface winds circulating around a central low pressure zone, which is called the eye. The wind speed within the eye zone is low and rapidly increases to a maximum, which is known as the eye wall. Outside of the eye wall, which is on the order of 10 km, the wind speed slowly decreases to the edge of the typhoon which is typically hundreds of kilometers from the eye.[1] The surface wind speed profile of a typhoon as a function of the range from the center is expressed as[10]

$$v(r) = \sqrt{AB(p_n - p_c)\frac{\exp(-A/r^B)}{\rho_a r^B}}, \tag{2}$$

where v is the wind speed at a height of 10 m above the sea surface (all of the wind speeds in this work are

*Supported by the National Natural Science Foundation of China under Grant No 11125420.
**Corresponding author. Email: lfh@mail.ioa.ac.cn
© 2015 Chinese Physical Society and IOP Publishing Ltd

at a hight of 10 m above the sea surface); p_c and p_n are the atmospheric pressure in the eye and outside of the typhoon, respectively; and, ρ_a is the air density, A and B are the empirical values affecting the maximum value of the wind speed and the radius of the eye zone. By using this model, the surface wind speed profile for a typhoon is given in Fig. 2.

Under the assumption that the monopole sources are uncorrelated, the received noise intensity at $(\boldsymbol{r}, z)$ radiated from $(\boldsymbol{r}_s, z_s)$ is written as

$$I(\boldsymbol{r}, z, f) = \int SI(\boldsymbol{r}_s, f)|g(\boldsymbol{r}, \boldsymbol{r}_s; z, z_s)|^2 d^2\boldsymbol{r}_s, \quad (3)$$

where $g(\boldsymbol{r}, \boldsymbol{r}_s; z, z_s)$ is the Green function. In a range-independent waveguide, the Green function can be expressed as the summation of normal modes,

$$g(R, z, z_s) = \frac{i}{\rho_w\sqrt{8\pi R}} e^{-i\pi/4} \cdot \sum_m \Phi_m(z_s)\Phi_m(z)\frac{e^{ik_m R}}{\sqrt{k_m}}, \quad (4)$$

with $R = |\boldsymbol{r} - \boldsymbol{r}_s|$; Φ_m and $k_m = \mu_m + i\beta_m$ are the complex eigenfunction and the eigenvalue of the mth mode, respectively.

By substituting Eqs. (1), (2) and (4) into Eq. (3), neglecting the coherent term of the normal mode, the noise intensity generated by a typhoon is expressed as

$$I(f) = \frac{1}{8\pi\rho_w^2}\sum_m \frac{|\Phi_m(z_s)\Phi_m(z)|^2}{\mu_m} \times \int_0^\infty \int_0^{2\pi} SI(R, \theta, f)e^{-2\beta_m R} dR d\theta. \quad (5)$$

If the eye of the typhoon is far from the receiver, then the term $e^{-2\beta_m R}$ decays more rapidly than the term $SI(R, \theta, f)$. Equation (5) can be further approximated as

$$I(f) \approx \frac{1}{8\rho_w^2}\sum_m \frac{|\Phi_m(z_s)\Phi_m(z)|^2}{\mu_m\beta_m} \times SI(f)_0, \quad (6)$$

with

$$SI(f)_0 = C(f) \times v_0^n, \quad (7)$$

where v_0 denotes the local wind speed above the receiver.

It should be noted that the predicted intensity from this derivation is accurate when the typhoon center is far from the receiver, more specifically, at least beyond the radius of the eye zone.

To verify the feasibility of the theory model, measured underwater noise intensity data are analyzed in the 100–1000 Hz frequency band as typhoon Krosa passed over a hydrophone in November 2013 in the South China Sea. The hydrophone was deployed on the sea floor with a water depth of around 1.1 km. The range from the center of the typhoon to the hydrophone is displayed in Fig. 3.

The position of the typhoon was published by the Central Meteorological Office on their official web site. It is shown in Fig. 3 that the typhoon passed by the hydrophone at a minimum range of 43 km.

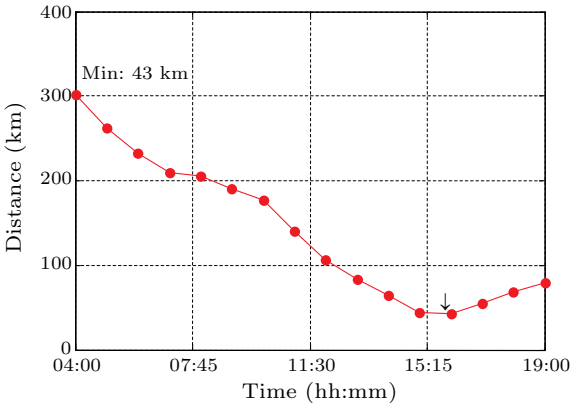

Fig. 3. Distance from the typhoon center to the receiver.

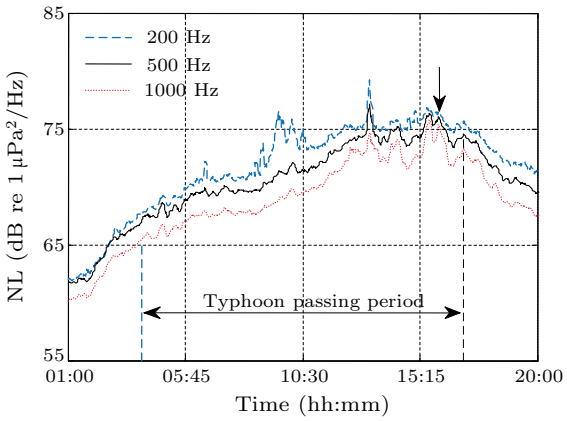

Fig. 4. The experimental noise intensity level.

The measured acoustic intensity at 200, 500 and 1000 Hz, shown in Fig. 4, exhibits a temporal structure with a maximum where the minimum range between the typhoon and the receiver occurred. Peaks between 09:00 and 11:00 at 200 Hz are produced by unknown mechanisms, and disappeared at higher frequencies.

It can be seen from Fig. 4 that the noise spectral intensity level increases as the eye approaches the hydrophone, and then decreases as the eye departs from the hydrophone, forming a peak marked with a down arrow, which corresponds to the moment when the minimum range occurs. The noise intensity of 200 Hz is about 3–4 dB higher than that at 1000 Hz when the typhoon is hundreds of kilometers away; however, the difference becomes smaller with the decreasing range and finally drops to 1 dB at the peak. This may be attributed to the complex components of noise at low frequencies (below 500 Hz, out of the wind-driven noise frequency band; such as sound from distant ships); however, at frequencies above 500 Hz, wind-driven noise always dominates the noise field.

Figure 5 shows the comparison between the predicted intensity and the measured intensity. The index n is chosen as $n = 3$ according to Ref. [1]. The predicted results at 200, 500, and 1000 Hz shown in Fig. 5 are in reasonable agreement with the experimental data from 04:00 to 13:00, corresponding to distances from 300 km to 80 km; however, the predicted results based on the model deviate from the experimental data when the distance is smaller than 80 km (from 13:00 to 17:00). The reason for this is that, when the typhoon is quite close to the receiver, the wind speed of the typhoon overhead (above the receiver) changes dramatically in a relatively small area, and then the approximation to the local wind speed (the wind speed at the receiver) may lead to deviations of the intensity estimation. In this case, the eye structure of the typhoon should be taken into consideration and the approximation of 'local wind speed' should be modified by other more complex approximations. A more accurate model taking consideration on advection of the characteristic morphology of the eye zone of a typhoon is under development, which can deal with a case where the typhoon is much closer to the receiver.

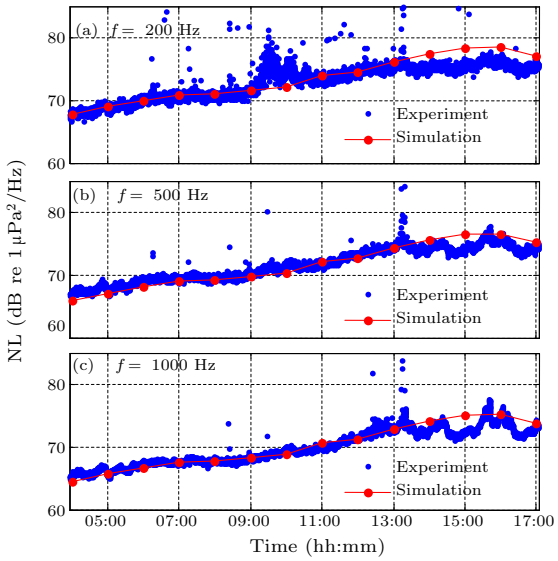

Fig. 5. The data/model comparison of the noise intensity.

It can be seen from Eqs. (6) and (7) that there is a power law relationship between the local wind speed v_0 and the underwater noise intensity I,

$$I(f) = v_0^n \times G(f), \tag{8}$$

where

$$G(f) = \frac{C(f)}{8\rho_w^2} \sum_m \frac{|\Phi_m(z_s)\Phi_m(z)|^2}{\mu_m \beta_m}. \tag{9}$$

Taking the logarithm of both sides of Eq. (8), Eq. (8) can be rewritten as

$$10\log_{10} I(f) = 10n\log_{10} v_0 + 10\log_{10} G(f), \tag{10}$$

where the logarithm of sound intensity is linearly related to the logarithm of the wind speed.

It is shown in Fig. 6 that there is a linear relationship between the logarithm of noise intensity and the logarithm of local wind speed. The measured noise intensity is proportional to the logarithm of the local wind speed with a slope of $n = 3$.

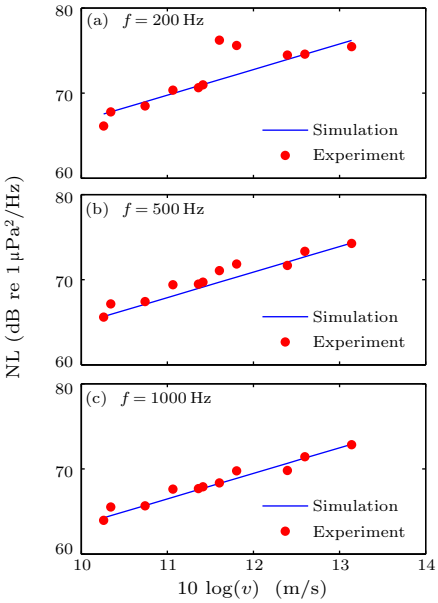

Fig. 6. The data/model comparison of the wind dependence.

In summary, an analytical typhoon-generated noise model is presented as a function of wind speed and frequency. The noise intensity generated by typhoons can be predicted accurately by using this model. Preliminary evaluations show that the simulation results are in reasonable agreement with the experimental data and the noise intensity is approximately proportional to the cube of the local wind speed. This model is still at a primary stage, and thus further derivation and extensive experimental data analyses are necessary.

References

[1] Wilson J D and Makris N C 2006 *J. Acoust. Soc. Am.* **119** 168
[2] Wenz G M 1962 *J. Acoust. Soc. Am.* **34** 1936
[3] Chan H C and Chen C F 2012 *Int. J. Remote Sens.* **33** 7398
[4] Burgess A S and Kewley D J 1983 *J. Acoust. Soc. Am.* **73** 201
[5] Chapman N R and Cornish J W 1992 *J. Acoust. Soc. Am.* **92** 782
[6] Ramji S, Latha G, Rajendran V and Ramakrishnan S 2008 *Appl. Acoust.* **69** 1294
[7] Vijayabaskar V and Rajendran V 2011 *Eur. J. Sci. Res.* **50** 28
[8] Nichols S and Bradley D L 2013 *Proc. Meetings Acoust.* (Montreal Canada 2–7 June 2013) **19** 070037
[9] Piggott C L 1964 *J. Acoust. Soc. Am.* **36** 2152
[10] Holland G J 1980 *Mon. Weather Rev.* **108** 1212