Gravitasi Vol. 23 No. 1 (June 2024) 27-32

Gravitasi

Journal available at: https://bestjournal.untad.ac.id/index.php/GravitasiFisika

e-ISSN: 2654-4318 p-ISSN: 1412-2375

Characteristics of ambient seismic noise in Southern Part of Sulawesi from BMKG and GSN network

W.O. Awaliah*, M. Rusydi, and S. Sandra

Department of Geophysical Engineering, Universitas Tadulako, Palu, Indonesia

Information

Article history:

Received: 11 June 2024

Accepted: 27 August 2024

Published: 30 August 2024

Keywords:

Ambient Seismic Noise
Cross Correlation
Surface Wave Tomography
Southern Part of Sulawesi

Abstract

Cross-correlations between stations for ambient seismic noise derived from 1 year of uninterrupted data in southern part of Sulawesi has been conducted. The main purpose of this study is to investigate the characteristics of ambient seismic noise and to determine the reliable period band for surface wave tomography. In this study we apply ambient noise analysis to vertical-component broadband data recorded by 11 stations deployed by BMKG and GSN network. Our results show that the ambient noise is dominantly coming from Flores Sea and Makassar Strait. The SNR > 5 is found at period between 8–30 s for most of interstation distance. The seasonal variation has not given significant impact, but strong ambient noise emerges when using recordings that are stack of 1 year in duration with data selection. We propose that the good period band EGF for surface wave tomography in southern part of Sulawesi is at period band 8-30 s.

*) e-mail: waodewaliah@gmail.com

DOI: 10.22487/gravitasi.v23i1.17152

1. INTRODUCTION

Two kinds of signals have been thought to create random wavefields in seismology. The first is known as seismic coda, and it arises when small-scale inhomogeneities scatter seismic waves more than once [1]. The second one is ambient seismic noise. As contrasted with seismic coda, ambient noise has the advantage of being recordable at any time and from any location, as it is not dependent on the occurrence of earthquakes.

Ambient noise is a seismic wave generated by environmental factors and human activity. Waves in the ocean and other atmospheric activity are some of the origins of seismic noise. These waves happened at random and spread in all directions. Nevertheless, according to [2], this kind of wave conveys information about the medium it passed through. Surface wave dominates this background noise.

Recently, surface wave tomography for Rayleigh waves based on the empirical Green's functions (EGF) obtained from cross correlations of ambient seismic noise has been applied successfully to real data at regional scales, such as in the western United States, South Korea, Tibet, New Zeland, Iceland, southern Africa, Netherlands, and Central Java, Indonesia [3-13]. The basic concept of ambient noise tomography is that, when recorded over extended periods of time, like a year, ambient seismic noise can be considered to be consisting of randomly dispersed wavefields. The sources of ambient noise would be distributed completely randomly, producing symmetric cross correlations with energy arriving at both positive and negative correlation lag times also known as the causal and acausal arrivals. However, in actual use, a notable asymmetry of the cross correlations is frequently seen, which is caused by closer or stronger ambient noise sources that are directed radially away from one station relative to the other. Therefore, to make sure that ambient noise tomography is being built on a solid foundation, a deeper understanding of the origin of ambient noise sources as well as their temporal and spatial distribution is required.

Every place on earth has different characteristics of ambient seismic noise. It depends on the condition of the area. The geological and stratigraphic conditions of the South Arm and Southeast Arm of Sulawesi significantly influence the characteristics of ambient noise, which are low-frequency seismic waves typically generated by natural processes like ocean waves and wind interactions with the Earth's surface. The southern part of Sulawesi Island, which includes the South Arm and the Southeast Arm, is geologically diverse and complex, reflecting its position within the tectonically active region of eastern Indonesia. This area is primarily characterized by ophiolitic complexes, metamorphic rocks, volcanic sequences, and sedimentary formations. These areas create a heterogeneous subsurface environment that affects the propagation of ambient noise [19-20].

Hence, we try to investigate the characteristics of ambient seismic noise in southern part of Sulawesi and to determine the reliable period band for surface wave tomography.

2. MATERIALS AND METHOD

This study uses waveform data recorded by 11 permanent seismic stations of Badan Meteorologi, Klimatologi, dan Geofisika (BMKG) and Global Seismograph Network (GSN) deployed in the southern part of Sulawesi (2 stations in the West of Sulawesi Province, 7 stations in the South of Sulawesi Province, and 2 stations in the Southeast of Sulawesi Province as shown in Figure 1a. Data is the seismogram vertical components with recording length of 1-year, between January to December 2016 as shown in Figure 1b and the example of raw data vertical component in station BKSI along 1-day is show in Figure 1c.

The data processing procedure applied here is similar to that described at length by [15] with some modification by [6,15]. Raw seismic data are processed 1-day at a time for each station after being decimated to 2 sample per second and the instrument response are removed using RESP files. Next, we perform spectral whitening using a running window approach, and band pass filter the data in the frequency domain. Then, we do temporal normalization cross-correlation for different bands separately to remove earthquake signals and instrumental irregularities prior to performing cross correlation. Then, we normalize the daily correlation functions (CFs) in different bands (2-5 s, 5-10 s, 10-20 s, and 20-40 s) and stack them together to form the broadband CFs. This may help to improve SNR of CFs in different bands than the normal one broadband processing [16].

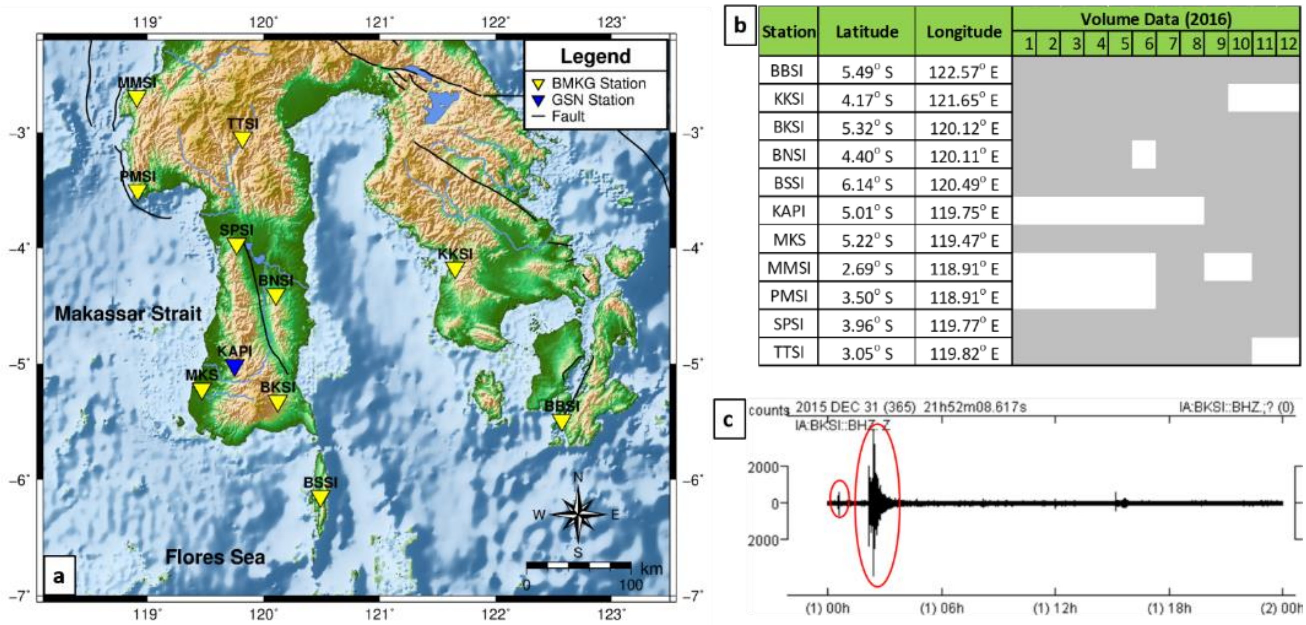

Figure 1. (a) Location map depicting seismic stations recording stations in the southern part of Sulawesi (b) The volume of daily data for 11 seismic stations of the network. The grey color indicates data is available and the white color indicates data is disable. (c) The example of raw data vertical component from station BKSI along 1-day showing a large of earthquake marked by the red circle.

In here, we only use 10 station pairs for sample to investigate the characteristics of the ambient seismic noise. Since our daily cross correlation function was not good perform for all of the daily data, we only stacked good quality data and removed the bad data. We implement this method to produce the CFs with good SNR as shown as in Figure 2. For example in station pair of BKS–BNSI stacked along 1-year without selection, the SNR was low and the amplitude decrease. However, when we do the selection of the data to be stacked, the SNR is very good and the amplitude is increasing. Finally, we can produce a good EGF. This is appropriate with the research conducted by [12], where there are some azimuths in most regions where ambient noise is so weak that interstation cross correlations will not provide a good EGF. From a practical perspective, therefore, these cross correlations have to be identified and removed as candidate EGF.

In ambient noise tomography, the empirical Green's Function (EGF) is derived from the cross-correlation of ambient seismic noise recorded at two stations. The general form of the cross-correlation to obtain the EGF is [18]:

$$\frac{dC_{AB}(t)}{dt} \approx -G_{AB}(t) + G_{BA}(-t) \qquad 1)$$

$G_{AB}(t)$ is the actual Green’s function at receiver B for a fictitious (point) source located at A, and $G_{BA}(-t)$ is the time-reversed Green’s function at A for a fictitious (point) source at B. In view of causality, $G_{AB}(t)$contributes at $t \geq 0$ and $G_{BA}(-t)$contributes at $t \leq 0$. Furthermore, $C_{AB}(t)$ is the approximate cross-correlation function between the stations given by:

$$C_{AB}(t) = \int_0^{tc} v_A(\tau) + v_B(t+\tau)d\tau \qquad 2)$$

where v_A(t) and v_{BA}(t) are the continuously recorded, but time windowed broad-band data at stations A and B, respectively, and t_C is the total cross-correlation time (i.e. observation time). The SNR is calculated using the following formula:

$$SNR = \frac{A_{signal}}{A_{noise}} \quad 3)$$

where, A_{signal} is the maximum amplitude of the Green's Function in the signal window, typically associated with the surface wave arrival. A_{noise} is the root mean square (RMS) amplitude of the noise in a separate noise window, where no signal is expected.

To investigate the characteristic of seismic ambient noise, we apply three scenarios. Firstly, we study about the azimuthal distribution of CFs to determine the origin of source noise at some band periods. Secondly, we apply the interstation distance of station pairs and measure the SNR to better understand about the peak of microseism. Thirdly, we implement seasonal variation and compare with 1 year stacking. After applying these scenarios, we determine the period band of EGF for surface wave tomography.

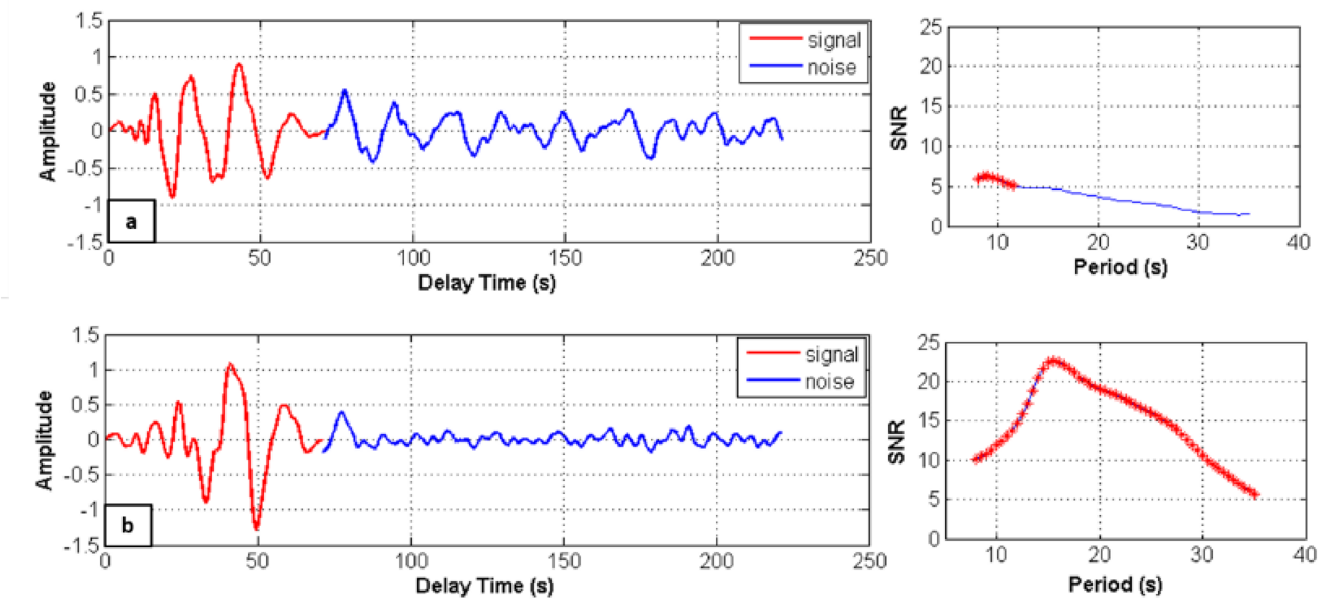

Figure 2. The result of cross-correlation between station BKSI and BNSI. The red stars on SNR indicate the SNR > 5. (a) Result of cross correlation of 1 year of data without selection (left) and values of SNR vs period (right). (b) Results of cross correlation of 1 year data with selection (left) and values SNR vs period (right).

3. RESULTS AND DISCUSSION

Based on Azimuthal Distribution

Based on azimuthal distribution, at period 8 – 30 s reveal a clear Rayleigh wave both on causal and acausal part. However, the noise source is dominantly coming from causal part (lag time positif) as shown an Figure 3a. In Figure 3b, when the BNSI station is cross correlated with stations that are more northerly, the most of noise sourse is coming from the southern and western part. While, when the BNSI station is cross correlated with the more south and west stations, the noise source comes from the southern part too. This suggests that the dominat ambient seismic noise is dominated by S-N and W-E trending.

We look that, both in the southern part and western part of South Arm of Sulawesi is surrounded by the ocean. In the southern part is Flores Sea and in the western part is Makassar Strait. Based on azimuthal distribution (the circle in Figure 3b), the strong of ambient seismic noise is coming from Makassar Strait and Flores Sea at period 8 – 30 s. This suggests the noise source asociated with the interaction of coastline and the ocean. Ambient seismic noise in short periods (T <20 s) is considered to be related the primary micro seismic activity associated with ocean wave interactions with the bathymetry of the ocean floor, whereas in the intermediate periods and long periods (T> 20 s) is associated with ocean gravitational waves [14].

Based on Interstation Distance

To understand the effect of interstation distances on ambient seismic noise characteristics in the South Arm of Sulawesi, we used cross correlation samples from station pairs of BNSI-KAPI, BSSI-BNSI, and BNSI-BBSI as shown in Figure 4.

In station pair of BNSI-KAPI with an interstation distance of 79 km, the SNR is almost evenly distributed from the period 8 - 30 s. Nevertheless, the SNR declined as the period increased. At the BSSI-BNSI station pair with an interstation distance of 198 km, the peak of SNR is in the period 22 s. At the BNSI-BBSI station pair with an interstation distance of 298 km, the peak of SNR is in the period 21 s. At BSSI-BNSI and BNSI-BBSI station pairs there are similar patterns. Where the peak of noise is in a period range that is not much different.

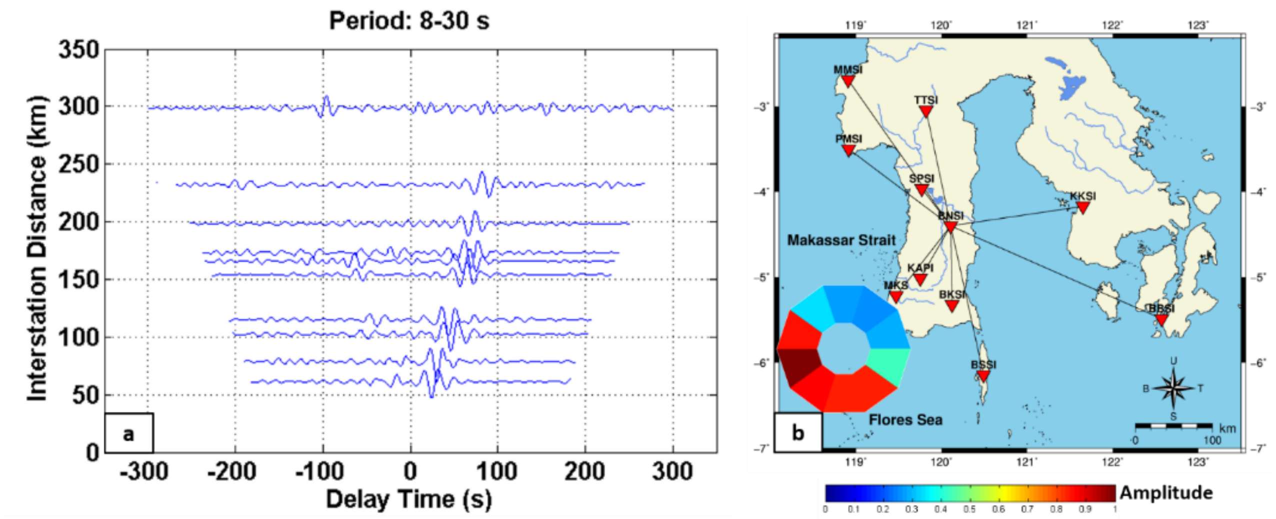

Figure 3. (a) The cross correlogram of statiun BNSI and the others (b) The azimuthal distrubution and the path segment of cross-correlation between station BNSI and the others.

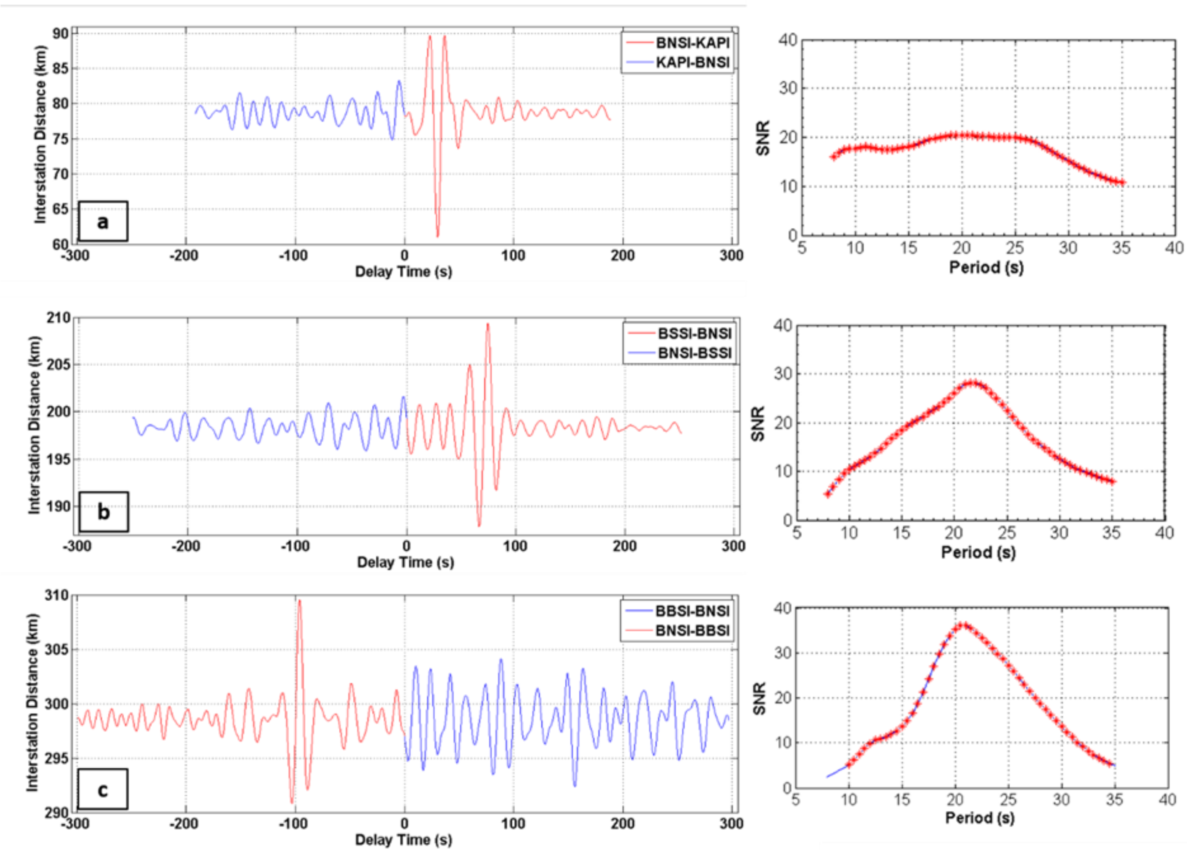

Figure 4. Cross correlation results based on interstatin distance (left) and SNR value (right (a) The results of cross correlation between station BNSI - KAPI with interstaoin distances of less than 100 km (b) Cross-correlation results between station BSSI – BNSI with interstation distances of approximately 100 km and less than 200 km (c) Cross-correlation results between station BNSI – BSSI with interstation distances of approximately 300 km.

Based on Seasonal Variations and Stacking 1 year Data

To explain the seasonal characteristics of seismic ambient noise in the Southern Arm of Sulawesi and its surrounding, we usedsamples from the results of cross-correlation between station BNSI and TTSI. Here we divide into three parts, as shown in Figure 5.

In Figure 5a. western season, the source of noise comes from BNSI stations with SNR greater than 5 in periods above 8 s, while in Figure 5b, the source of noise is also coming from station BNSI with SNR greater than 5 in periods above 8 s. The interesting thing about Figures 6a and 6b is that the highest SNR peaks are the same is in the period around 13 – 15 s. Of course, this can be associated with primary microseism, where the peak noise is in the period 10 - 20 s [12,14,17]. However, when we do stacking by combining data from both seasons in this one year, the SNR is evenly distributed. This suggests that the noise source is evenly distributed at almost every period and its SNR is further increased. Starting from the period 10 - 30 s, the SNR is more than 10. This indicates the seasonal variation hasnot given significant impact but strong ambient noise emerges when using recordings that are stack of longer time duration with selection data.

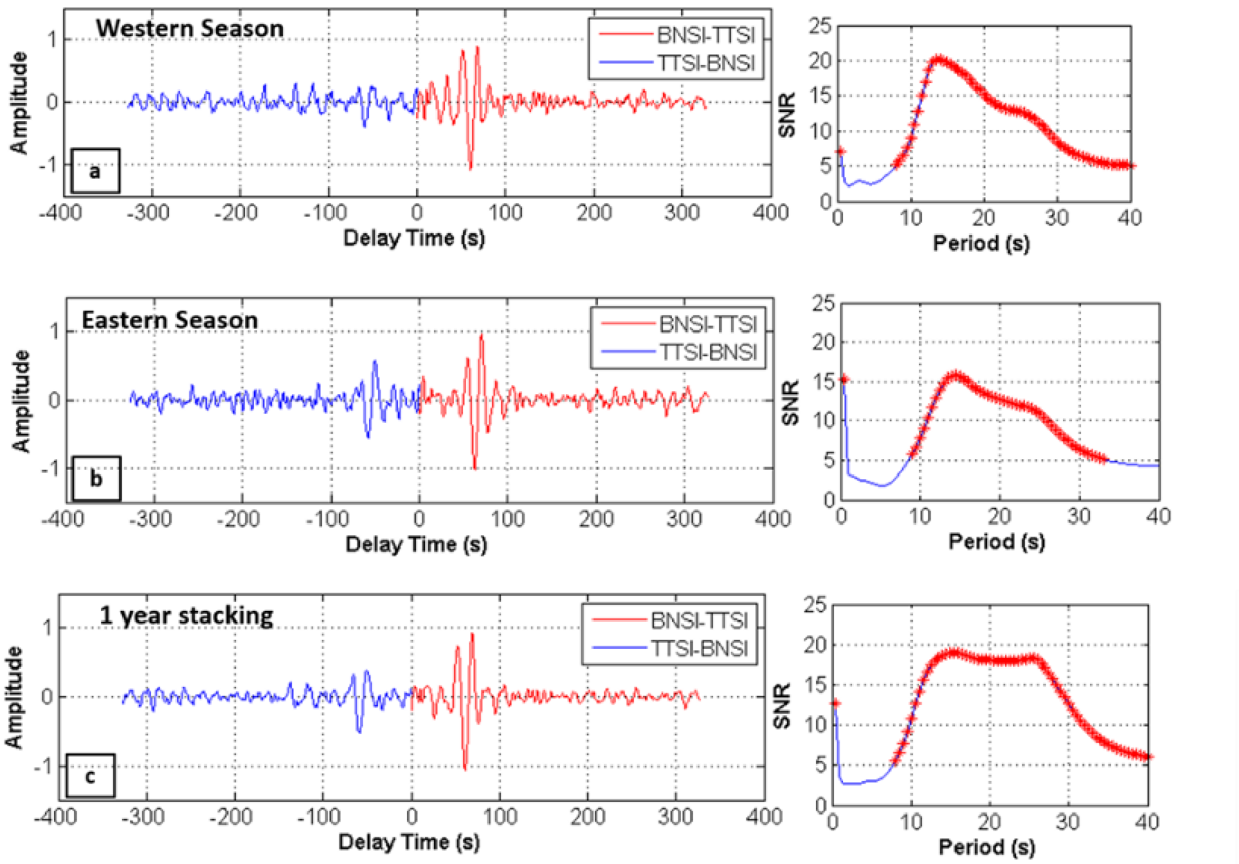

Figure 5. The result of cross correlation between stations BNSI and TTSI (left) and its SNR values in the period 0 - 40 s (right). The red color in the cross correlation results shows the source of noise comes from station BNSI to TTSI while the blue color indicates the noise spreading from station TTSI to BNSI. In SNR the red start indicates that the SNR is greater than 5 at each period (a) The result of cross correlation in the western season and its SNR value(b) The result of cross correlation in the eastern season and its SNR value (c) The result of cross correlation during the 1 year duration its SNR value.

4. CONCLUSION

Ambient noise cross correlation functions by using the data from BMKG and GSN network has been reveal successfully clear Rayleigh wave propagation between each station pair, in the broad period band 8–30 s. The source of ambient noise is dominantly coming from Flores Sea and Makassar Strait and it relates with the primary microseism. The SNR > 5 is found at period between 8– 30 for most of interstation distance. The seasonal variation has not given significant impact but strong ambient noise emerges when using recordings that are stack of longer time duration with selection data. Next, our result is reliable for the EGF and surface wave tomography.

5. ACKNOWLEDGMENT

We thanks to Dana DIPA FMIPA Universitas Tadulako who has funded this research so that this research can be done smoothly. We also thank Prof. Huajian Yao, who provided us with ANT processing software. Thanks to Badan Meteorologi, Klimatologi, dan Geofisika (BMKG) and Global Seismograph Network (GSN) for providing online waveform data access.

REFERENCES

[1] Paul, A., M. Campillo, L. Margerin, E. Larose, and A. Derode 2005, Empirical synthesis of time-asymmetrical Green functions from the correlation of coda waves, *J. Geophys. Res.*, **110**, B08302.

[2] Wapenaar, Kees & Draganov, Deyan & Snieder, Roel & Campman, Xander & Verdel, Arie 2010, Tutorial on seismic interferometry. Part I: Basic principles and applications. Geophysics. 75. 75A195-75209. 10.1190/1.3457445.

[3] Shapiro N M, Campillo M, Stehly L and Ritzwoller M H 2005 Science **307** 1615–1618

[4] Sabra K G, Gerstoft P, Roux P, Kuperman W A and Fehler M C 2005 Geophys. Res. Lett **32** L14311

[5] Moschetti M P, Ritzwoller M H and Shapiro N M 2007 Geochem. Geophys. Geosyst. **8** Q08010

[6] Lin F, Moschetti M P, and Ritzwoller M H 2008 Geophys. J. Int., in press

[7] Cho K H, Herrmann R B, Ammon C J and Lee K 2007 Bull. Seismol. Soc. Am. **97** 198–207.
[8] Yao H, van der Hilst R D and de Hoop M V 2006 Geophys Journal-Oxford **166** 732–44
[9] Lin F, Ritzwoller M H, Townend J, Savage M and Bannister S Geophys. J. Int. **170** 649–666
[10] Gudmundsson O, Khan A and Voss P 2007 Geophys. Res. Lett. **34** L14314
[11] Yang Y, Ritzwoller M H, Levshin A L and Shapiro N M 2007 Geophys. J. Int. **168** 259–274
[12] Yudistira T, Paulssen H and Trampert J 2017 Tectonophysics **721** 361-371
[13] Zulfakriza Z, Saygin E, Cummins P R, Widiyantoro S, Nugraha A D, Lühr B G and Bodin T 2014 Geophys. J. Int. **197** 630–5
[14] Yang Y and Ritzwoller M H 2008 Geochem. Geophys. Geosyst. **9(2)** Q02008
[15] Bensen G D, Ritzwoller M H, Barmin MP, Levshin A L, Lin F, Moschetti M P, Shapiro N M and Yang Y 2007 Geophys J.Int. **169** 1239-1260
[16] Yao H, Gouedard P, McGuire J, Collins, J and van der Hilst R D 2011 Comptes Rendues Geoscience de l'Académie des Sciences **343** 571–583.
[17] Nishida K 2017 Proc Jpn Acad Ser B Phys Biol Sci. **93(7)** 423-448
[18] Yao, H., Wu, R.-S., & Chen, Z 2006. *Geophysical Journal International*, *166*(2), 732-744.
[19] Hall, R 2012 *Tectonophysics, 570-571*, 1-41.
[20] Parkinson, C. D 1998 *Journal of Asian Earth Sciences*, *16*(1), 13-28.