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Distribution and Characteristics of Internal Waves Observed During the Expedition of Jalacitra 2-2022 Banda

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Abstract

Indonesian seas have been known as the hotspot for internal waves (IWs) generation sites. The sinking tragedy of the Indonesian Naval Submarine, KRI Nanggala 402 on 21 April 2021 in the northern Bali Sea was highlights the need of detecting, mapping, and characterizing internal waves in Indonesian waters are compulsory mainly in the Indonesian Archipelago Sea Lanes (IASLs). IASLs is a gateway for sea crossings which can be used by civil navigations, intercontinental trade, and foreign military. This study focused on mapping the distribution and characteristics of internal waves qualitatively using EA 600 Single beam Echosounder (SBES) of the Indonesian Naval Vessel, KRI Rigel 933 during The Jala Citra Expedition 2-2022 Banda. The measurements were conducted around the IASLs route in the Bali Waters, Banda Waters and Buru Waters. The results show that the typical high-frequency non-linear internal waves (HFNWs) with an amplitude of less than 10 m were observed intermittently during the expedition, detected mostly in the narrow passages, rough topography and shallowing waters. Typical characteristics of internal solitary waves (ISWs) were also observed with typical amplitudes of ~20 – 65 m. An ISWs extreme events found in this study verified the "turbulent water" that was reported in in the IASLs around the Underwater Seamount (US) Nieuwerkerk waters, in 1925 during the Snellius Expedition. The detection of internal wave events using acoustic equipment, the single beam echosounder is considered effective which can later be used as the guidance for marine activities in the water column.

Keywords: *Indonesian Seas, internal waves, singlebeam echosounder, jala citra, turbulent water*

Introduction

Indonesian seas have been known as the marine/ocean park for internal waves (IWs) generation sites, such as: Bali Waters (Lombok Strait) (Karang *et al.,* 2012; Pratomo *et al.,* 2016; Brown *et al.,* 2019; Syamsudin *et al.,* 2019; Chonnaniyah *et al.,* 2021, 2023; Gong *et al.,* 2022a; Purwandana *et al.,* 2021, 2023), Sulawesi Waters (Nugroho *et al.,* 2018; Wattimena *et al.,* 2018; Purwandana *et al.,* 2022); Maluku Waters (Firdaus *et al.,* 2021; Purwandana and Cuypers, 2023), North Aceh Waters (Prasetya *et al.,* 2021; Sun *et al.,* 2021) and Banda Waters (Atmadipoera *et al.,* 2022). The presence of IWs in Indonesian seas requires a comprehensive understanding in terms to identifying their characteristics (Wang *et al.*, 2022), it is urgently needed to support the safety of underwater navigation (La Forgia *et al.,* 2019, 2020; Stepanyants, 2021; Purwandana and Cuypers, 2023), underwater constructions (Dong *et al.*, 2016; Zhang *et al.*, 2019) and its sustainability for the waters abundance (Hung *et al.,* 2021; Purwandana *et al.,* 2022; Situmorang *et al.,* 2022; Wang *et al.,* 2022). The effects of IWs can rising seawater mass, the characteristics of seawater mass in our study area from can be found and well explanation by Atmadipoera *et al.* (2009, 2022); Purwandana *et al.* (2021); and Purba *et al.* (2024), due to these waves carry considerable energy (depending on the amplitude) which can affect the stability of an object both in the horizontal and vertical directions (Fan *et al.,* 2021; Song *et al.,* 2021; Sun *et al.,* 2021). The sinking tragedy of the Indonesian Naval Submarine, KRI Nanggala 402 on 21 April 2021 in the northern Bali Waters is a negative impact of IWs (Gong *et al.,* 2022a; Stepanyants, 2021; Wang *et al.,* 2022), specifically for maritime defense. On the other hand, the positive effect of the presence of internal waves is the occurrence of a natural mechanism to

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distribute tidal energy from generating source area to other waters area; as well as being an important contributor that supports water abundance when it breaks in coastal areas. Its presence on the coast can trigger the flow of nutrients (nutrients) vertically so as to support primary productivity (Pranowo *et al.,* 2005; La Forgia *et al.,* 2019, 2020; Hung *et al.,* 2021). IWs can arise from three factors: the generating of barotropic internal tides, complexity of topography (such as sills or underwater seamounts), and the existence of stratified seawater. The necessary conditions for the formation of internal waves can be observed in most Indonesian waterways (Susanto *et al.,* 2005; Nagai and Hibiya, 2015; Purwandana *et al.,* 2021; Gong *et al.,* 2022b; Situmorang *et al.,* 2022; La Forgia *et al.,* 2023).

In 1925 during the Snellius Expedition it was reported a "turbulent water" in the IASLs around the US Nieuwerkerk waters at a position of 6°40' S and 124°41'E with approximately 2 km from the ship's position when sailing, it is suspected to be IWs. Research combination based on Synthetic Aperture Radar (SAR) images and numerical modelling (Masunaga *et al.,* 2015; Chonnaniyah *et al.,* 2021; Prasetya *et al.,* 2021; Purwandana *et al.,* 2022; Wang *et al.,* 2022; Purwandana and Cuypers, 2023) still requires validation from the results of direct observations (*in situ* data) in waters that are suspected of presence an internal wave phenomenon, because the results of the acquisition of satellite image data cannot explain the effect of internal waves on the water column, while the numerical model requires a qualitative value in order to obtain an estimate of the amplitude value, so that it can explain the level of suitability of the model and the results of *in situ* observations. Based on the Snellius Expedition information for allegation of IWs activity on US Nieuwerkerk waters and limited understanding to analyzes the characteristics of ISWs (on water column) in the Indonesian Seas (IS) by surveying satellite remote sensing images and numerical model, Hydrographic and Oceanographic Center of The Indonesian Navy conducted Jala Citra Expedition 2-2022 "Banda", which aims to find out more comprehensively the application of acoustic equipment to identify water column phenomena (i.e. IWs) on IS, because acoustics are tools used in navigation activities, underwater warfare and water column is battle zone for marine soldier. The application of this technology in various purposes, such as research, hydrography, mapping of marine habitats, military, fisheries, oceanography, monitoring of climate change and geology of the seabed (Colbo *et al.*, 2014; Syamsudin *et al.*, 2019).

This paper analyzes distribution and characteristics of IWs observed during the Expedition of Jalacitra 2-2022 around the IASLs route in the Bali Waters, Banda Waters and Buru Waters (see

Figure 1, denote by blue star) qualitatively using EA 600 SBES of the Indonesian Naval Vessel, KRI Rigel 933, which is the vessel track paths. This study found water column anomalies that suspected IWs in those three areas. The interesting thing revealed in this article is that IWs can be detected with SBES eventhough the naval vessel is moving, in contrast to previous studies that carried out observations of IWs with ships in moored at a certain area alleged as generating source (Susanto *et al.,* 2005; Lien *et al.,* 2014; Purwandana *et al.,* 2022, 2023; Situmorang *et al.,* 2022), the discovery of new insights on the use of SBES and the identification method of IWs as a result of this expedition is greatly helpful for military submarines in war and navigation activities. The outcomes of this expedition are also anticipated to raise awareness regarding the significance of hydro-oceanographic spatial and temporal data in attaining maritime excellence and sovereignty in IS.

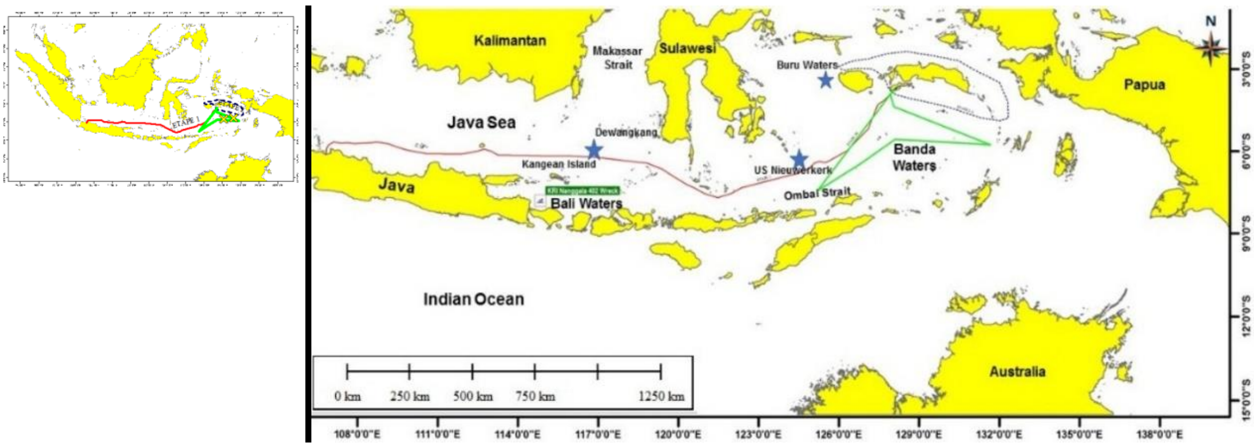

Figure 1. Study Area (star symbols) and naval vessel track paths during Jalacitra Expedition 2-2022 "Banda" (1st etape: red line; 2And etape: blue line and 2Bnd: green line)

Materials and Methods

Water Column Imaging (WCI) data acquisition (In-situ observations)

Data collecting in the field took place in from July 2022 to August 2022, *i.e.*, as long as Jala Citra Expedition 2-2022 "Banda" was held in the Banda Sea and surrounding water, using Indonesian Naval Vessel, KRI Rigel 933 under the Hydrographic and Oceanographic Center of The Indonesian Navy, coincides with the southeast monsoon season (dry season) in IS. Throughout the process of recording acoustic data, the vessel's speed was consistently maintained at an approximate range of 3 to 8 knots, as mandatory by IHO (2010). In addition, the IHO (2010) is required to tackle the issue of correcting the sound waves emitted by hydrographic acquisition equipment (SBES). This can be achieved by utilizing the sound velocity profile (SVP) data obtained from CTD equipment in the vicinity where bathymetry and water column data are gathered. Throughout the voyage, the SVP value varied from around 1487 $m.s^{-1}$ in the deep layer to 1538 $m.s^{-1}$ in the surface layer. The average depth ranged from 0 to 2000 m. To ensure correct depth information, we configured the sound velocity in the research region such that the acoustic waves from the SBES could effectively reach the bottom of the sea. After the completion of the instrument calibration phase, the SBES was then employed for the measurement process. The data used for identifying IW is produced by capturing and recording Water Column Imaging (WCI) using acoustic equipment, specifically the SBES mounted aboard the KRI Rigel. The SBES is located in a 1 m-long "gondola" beneath the ship keel and is always submerged below the sea surface. The data is obtained through the direct emission of sound waves and subsequent recording of the reflections received from the water column. Measurements were collected constantly along the ship's sailing course during the expedition, with a sampling interval of 20 seconds. The data was acquired by operating the Kongsberg Maritime Type EA 600 SBES at a constant frequency of the pings was set 50 kHz while the ship was moving. Data measurements were done along the IASL path in the Bali Waters, Banda Waters, and Buru Waters, as shown in

Figure 1. The SBES data produced a file with the *.raw extension, which was analyzed using the Kongsberg Maritime EA640 Echosounder v.16.3.2 software. The collected data consists of backscatter values, which are represented as an image of the water column. This image is subsequently examined to identify the presence of IWs. The primary emphasis in this context is on gathering and analyzing acoustic data for the purpose of hydrographic and oceanographic studies. This technology enables precise mapping of the characteristics of the water column in the investigated region during the expedition period.

Oceanographic parameters dataset

Physical oceanographic parameters such as salinity, temperature, eastward sea water velocity (*uo*), Brunt-Vaisala frequency, and potential density anomaly were obtained from the Marine Copernicus (MC) data available at https://data.marine.copernicus.eu/product/global_analysisforecast_phy. The data model was processed using ODV (Ocean Data View) V.5.2 software to get a summary of physical oceanographic parameters, especially from sea level to a depth of ~300 m to see the stratification of change in the water column. In addition, tidal dataset with harmonic constituents, as follows: M2; S2; N2; K1; O1; P1; Q1; M4; Ms4; Mn4; Mm; and Mf were obtained from OTIS (Oregon State University Tidal Inversion Software) tidal data (Purwandana and Cuypers, 2022), is used to reconstructing tides when the emergence of IWs in study area, especially during periods of the Snellius Expedition in 1925 and Jala Citra Expedition in 2022.

Data analysis

The first method is using the SBES data. The data analysis method in this study to justify the characteristics and distribution of internal waves is carried out qualitatively. All acquisition data of SBES during expedition were processed using Kongsberg Maritime EA 640 Echosounder v.16.3.2 software with a depth range which is analyzed at a depth of 0–300 m (Purwandana *et al.*, 2021) and the initial intensity value of decibels is set in the range -55 to -70 dB (Situmorang *et al.,* 2022) but in order to clarify the visual description of the IWs in the water column, the decibel intensity value is set to a range of -80 to -90 dB (see Figure 2.). Once the processed data from SBES clearly showed the presence of IWs in the water column, the characterization of IWs using the Korteweg-de-Vries (K-dV) equation, adhering to the Purwandana and Cuypers (2022) method, is as follows:

$$\frac{\partial \eta}{\partial t} + c\frac{\partial \eta}{\partial x} + \alpha\eta\frac{\partial \eta}{\partial x} + \beta\frac{\partial^3 \eta}{\partial^3 x} = 0$$

The typical wave of depressions revealed several waves with large significant amplitudes at several locations, the echosounder signal were used to fit the

KdV solitary waves solution amplitude *η₀* (dash pattern in Figure 4. and Figure 7.). Furthermore, the position of the visual appearance of the IWs is mapped using Global Mapper v.19 to obtain the distribution of the location of the IWs propagation.

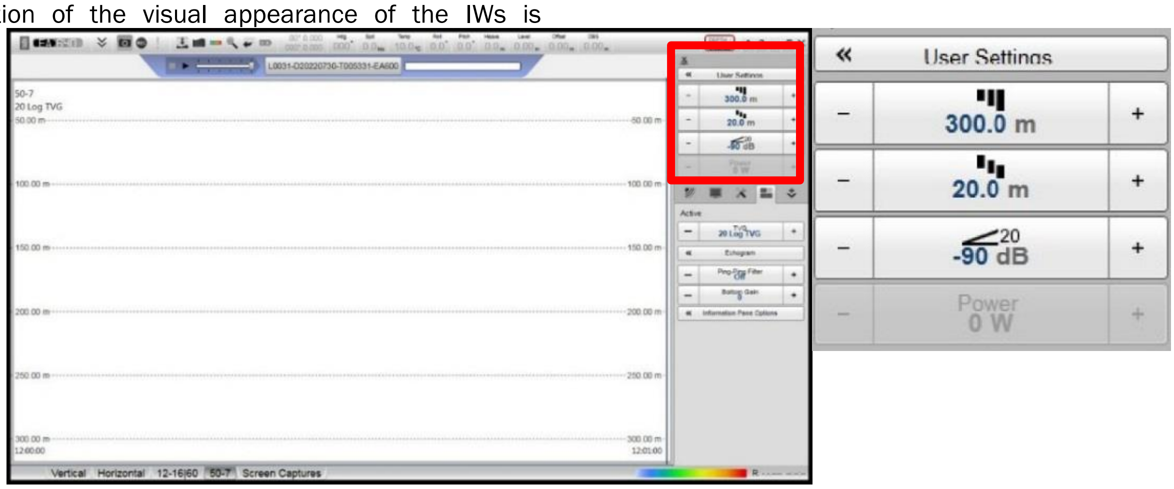

Figure 2. Setting parameters on Kongsberg Maritime EA 640 Echosounder v.16.3.2 software to identify IWs

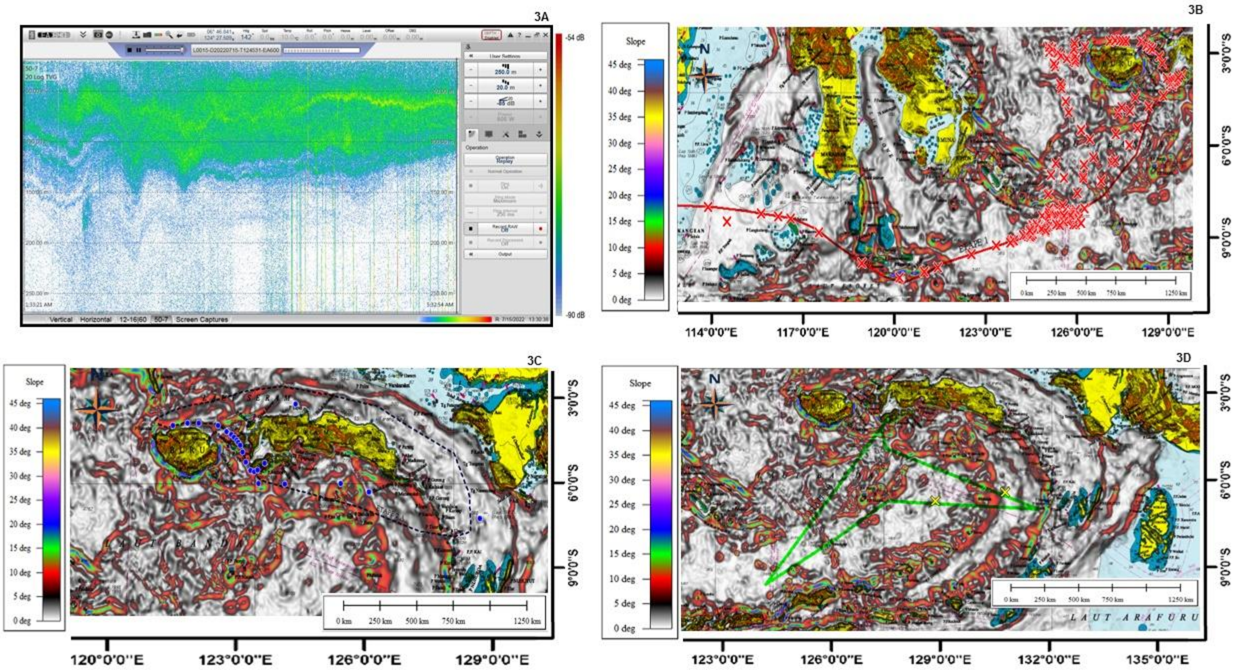

Figure 3. Visualizations water column from Kongsberg Maritime EA 640 Echosounder v.16.3.2 software (3A) and suspect of IWs distributions from naval vessel track paths during Jalacitra Expedition 2-2022 "Banda" as follow: 1st etape: denote by red line & red cross (3B); 2And etape: denote by blue line & blue dots (3C); and 2Bnd: denote by green line & yellow cross (3D).

Result and Discussion

Distribution of IWs

IWs form in the deep ocean tend to be sinusoidal pattern, qualitatively carried out to determine the characteristics of IWs detected (Fan *et al.,* 2021; Situmorang *et al.,* 2022) from SBES data during expedition. The amplitude of can be measured by calculating the difference in depth from the crest of the wave to the base of the crest. The appearance of IWs is also influenced by topographical shape or obstacle, which occurred by interactions between barotropic tidal currents and underwater topography in stratified water (Masunaga *et al.,* 2015; Nugroho *et al.,* 2018; Gong *et al.,* 2022a; Purwandana *et al.,* 2022; Situmorang *et al.,* 2022; Wang *et al.,* 2022). The prominent topographic influence is the slope of the topographical shape or obstacle when the internal tide current passes through the critical and supercritical topography (Nagai and Hibiya, 2015; Bouruet-Aubertot *et al.,* 2018). In this study, we use the General Bathymetric Chart of the Ocean (GEBCO) product which can be downloaded at https://www.gebco.net/data_and_products/ to

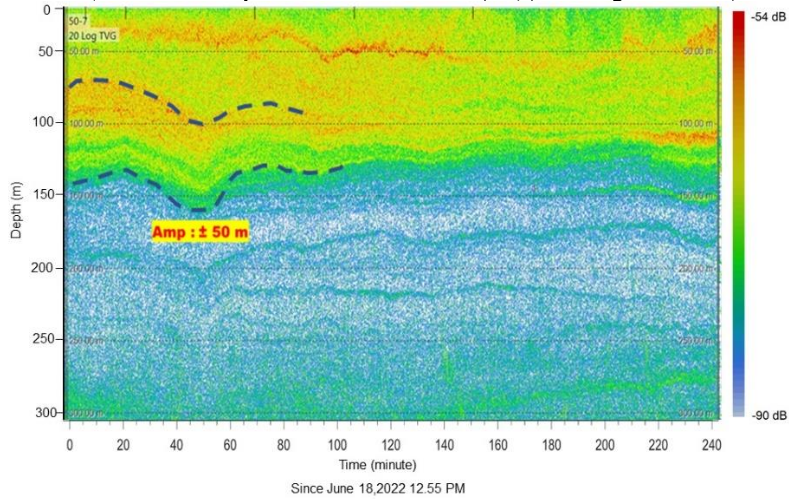

Figure 4. Measurement results of Single beam Echosounder EA600 50 kHz which shows the appearance of IWs packets with ~50 m amplitude height on June 18, 2022, at position 6.2° S-116.2° E around Bali Waters to Dewangkang Water (see Figure 1.).

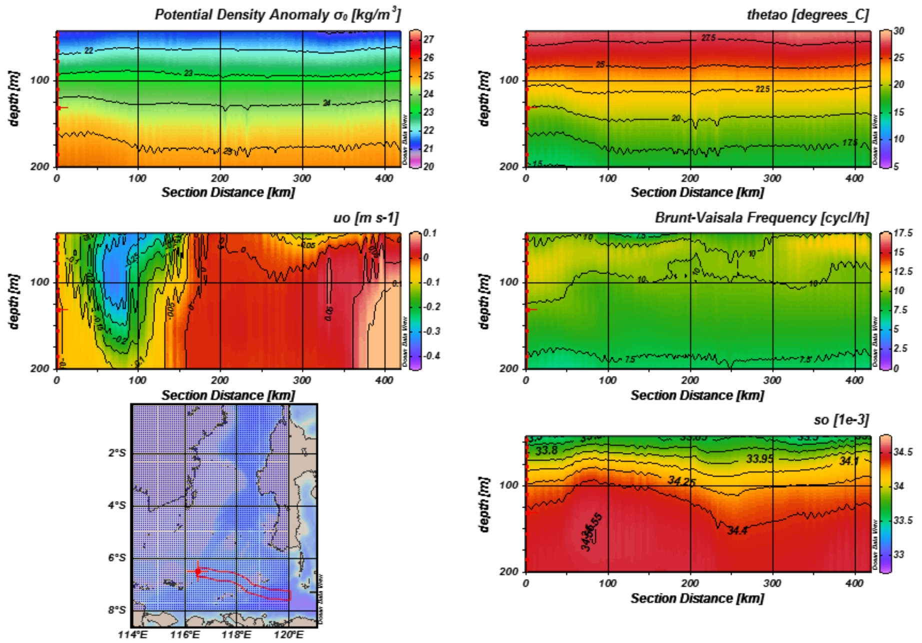

Figure 5. Physical oceanographic parameters in the form of salinity, temperature, and density from sea level to a depth of 300 m to see the stratification of change in the water column from MC along the Jala Citra Expedition vessel track on June 18, 2022, around Bali Wates to Dewangkang Waters

determine the topographical slope of the seabed, based on this data, IS have a slope value ranging from ~6° to 15 °.

Qualitative analysis based on the results of the visualization of sinusoidal shape anomalies that occur in the water column in the SBES data during the Jalacitra Expedition 2-2022 "Banda" and the influence of slope due to topographic complexity from previous studies, we hypothesize that the anomalies contained in the SBES data processing are believed to be IWs, which propagate and reflect due to topographic changes (slope) (Prasetya *et al.*, 2021; Purwandana *et al.*, 2022). In addition, one of the properties of IWs is to emit radiation (rays) from the topography (Sun *et al.,* 2021; Purwandana *et al.,* 2022; Purwandana and Cuypers, 2023). The distribution of IWs presented in Figure 3 is very reasonable to occur in the waters of eastern Indonesia, considering that these waters are the main

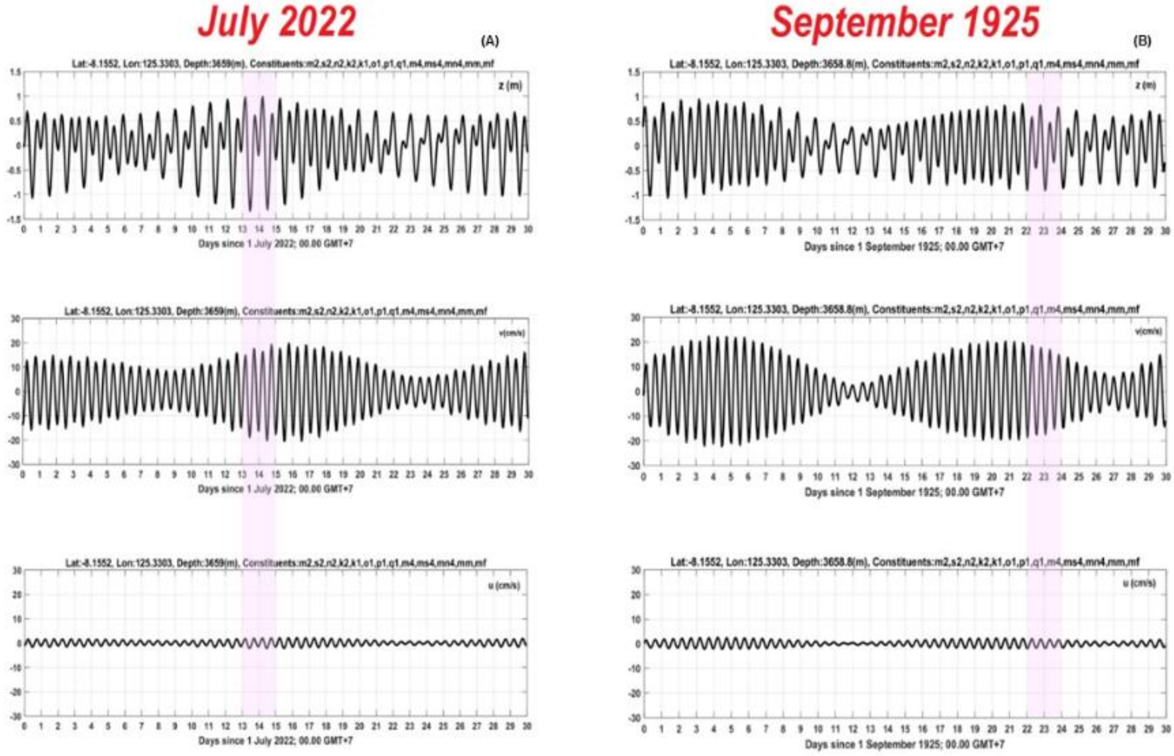

Figure 6. Predicted tides inferred from Oregon State University Tidal Inversion software (OTIS) during the Jala Citra Expedition period (a) and during the Snellius Expedition (b) around Ombai Strait at position 8.1° S -125.3° E, using tidal harmonic constituents, as follows: M2; S2; N2; K1; O1; P1; Q1; M4; Ms4; Mn4; Mm; and Mf

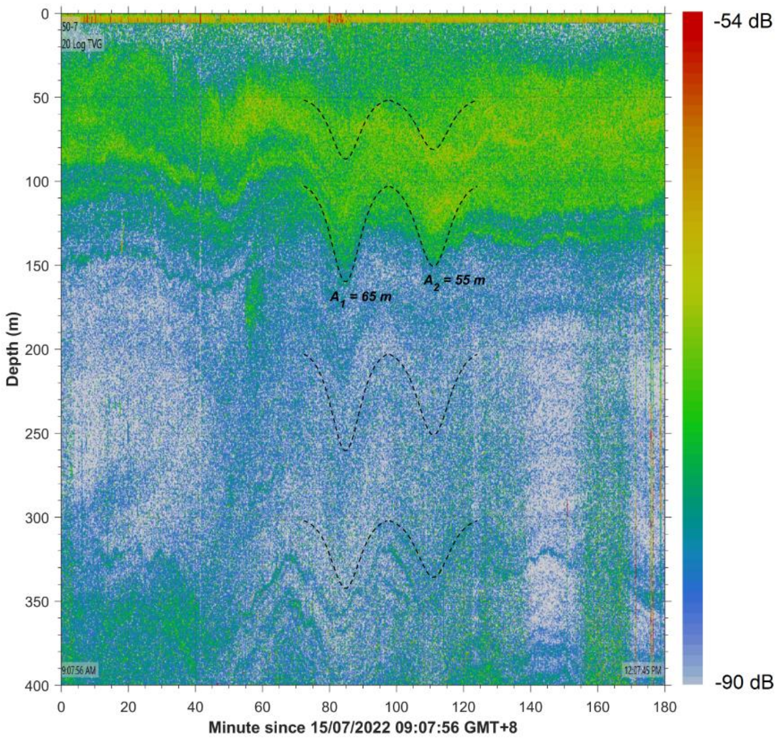

Figure 7. ISWs packet detected by *Single Beam Echosounde*r EA600 50 kHz result from Jala Citra Expedition on July,15 2022 at a position 6.8° S - 124.5° E in US Nieuwerkerk

routes for the ITF (Indonesian Through Flow) that carries water masses from the Pacific Ocean to the Indian Ocean (Gordon, 2005; Atmadipoera *et al.,* 2009; van Aken *et al.,* 2009; Gordon *et al.,* 2019; Lee *et al.,* 2019; Sprintall *et al.,* 2019; Apriansyah and Atmadipoera, 2020; Purwandana *et al.,* 2020).

Characteristic of IWs

Amplitude of IWs on Jalacitra Expedition 2-2022 "Banda" results show that the typical of HFNWs with an amplitude of less than 10 m were observed intermittently during the expedition, detected mostly in the narrow passages, rough topography, and shallowing waters. Typical characteristics of ISWs were also observed with typical amplitudes of ~20 – 65 m. The existence of IWs in IS caught in most of the narrow passage, this passage is part of IASLs which is a sea lane to enter Indonesian territorial waters, so it is makes IWs absolutely need to be studied more comprehensively, because this has direct implementation for defense and security at sea.

Bali Waters (around Lombok Strait to Dewangkang)

Propagation of IWs in this area depend on previous study, especially using image satellite, state that direction of IWs are going to northwest (Kangean Island) (Jayanti *et al.*, 2024) around KRI Nanggala 402 wreck site (see

Figure 1.) and be fathomed the generating source from Lombok Strait (Gong *et al.*, 2022a; Wang *et al.*, 2022), In addition, there is also IWs propagation which tends to lead to the northeast, towards the Makassar Strait around the Dewangkang Waters (Karang *et al.,* 2012; Brown *et al.,* 2019; Chonnaniyah *et al.,* 2021; Chonnaniyah *et al.,* 2023; Purwandana *et al.,* 2023). Jalacitra Expedition results show that the typical of ISWs occurs in Dewangkang Waters with with an amplitude value of ~ 50m (Figure 4.).

In this study area, using the MC dataset aimed to analyze the water mass characteristics in the IWs region. A summary of physical oceanographic parameters, including salinity, temperature, and density, from sea level to a depth of approximately 300 m, was conducted to observe and analysis the stratification and changes in the water column, as an analysis of the possible presence of IWs in the waters from Bali Wates to Dewangkang Waters along the shipping route occurred on June 18, 2022. The data processing results of the MC model also revealed a *wavy pattern* along the area where the ship is pointing passed the Jala Citra Expedition (see

Figure 5.). Wave formation in the waters of Dewangkang as a result of the expedition based on the model developed by *Gong et al.* (2022b) with the K-dV method is classified as occurring at stage 3 (a review of these processes illustrated with K-dV model can be found in Gong *et al*. (2022b)), because the developed model only covers areas with a latitude 7°S to 9.5°S, so a comprehensive analysis is still being carried out because the wave packet is located at the coordinates of 6°14`28.80" S - 116°48` 59.40" E and found depth ~ 150 m above sea level. Although there is a difference in latitude, the energy of the ISWs can still be captured by the leading wave, where the position of the phenomenon is in the main path of ITF with a water depth of ~ 300 m.

Banda waters (US Nieuwerkerk)

The Snellius Expedition in 1925 was reported a "turbulent water" in the IASLs (Nugroho *et al.,* 2018; Nagai and Hibiya, 2015, 2020; Darmawan *et al.,* 2020) around the US Nieuwerkerk waters at a position of 6°40' S and 124°41'E. Mitnik and Dubina (2009) stated that there are 3-4 consecutive IWs packets from the Aqua MODIS satellite imagery that are generated when the semidiurnal tides increase and this can be clearly observed when the conditions are not cloudy, thus identifying the origin of the IWs packets, where IWs packets is originate from the Ombai Strait, which may generated an upward and downward current velocity (Kurniawan *et al.*, 2023) and extend towards the US Nieuwerkerk.

During the Jala Citra Expedition period (July 2022) and the Snellius Expedition (September 1925) showing that both expeditions were carried out during the spring tide period (

Figure 6.), tidal data was derived from OTIS. In addition, the capes or islands around Ombai Strait, makes the mass flow of water entering from the Indian Ocean increase the speed and energy of the current, before encountering topographical obstacles such as shelf, it can propagate over several hundreds of km, then they can break and reflect (Mitnik and Dubina 2009; Purwandana *et al.* 2022), where the distance between Ombai Strait and US Nieuwerkerk is ~180 km. ISWs detected by *Single Beam Echosounde*r EA600 50 kHz result founds 2 packets with amplitude high ~55 to 65 m (Figure 7) in US Nieuwerkerk which is also the 3rd IASLs of Indonesia. We hypothesized that the turbulent water that occurred in Snellius Expedition was actually an ISWs packet that had been reflected and breaking due to topographical obstacles, in the presence of the US

(Nieuwerkerk), show in Figure 8, and propagate towards to Banda Waters.

Buru waters

ITF, which transports water from the low latitude Pacific Ocean through the Indonesian sea to the eastern Indian Ocean (Lee *et al.*, 2019), has three main routes entering Indonesia's territorial waters, one of which is through the Maluku Sea and splits around the Lifamatola Strait, this passage is knows

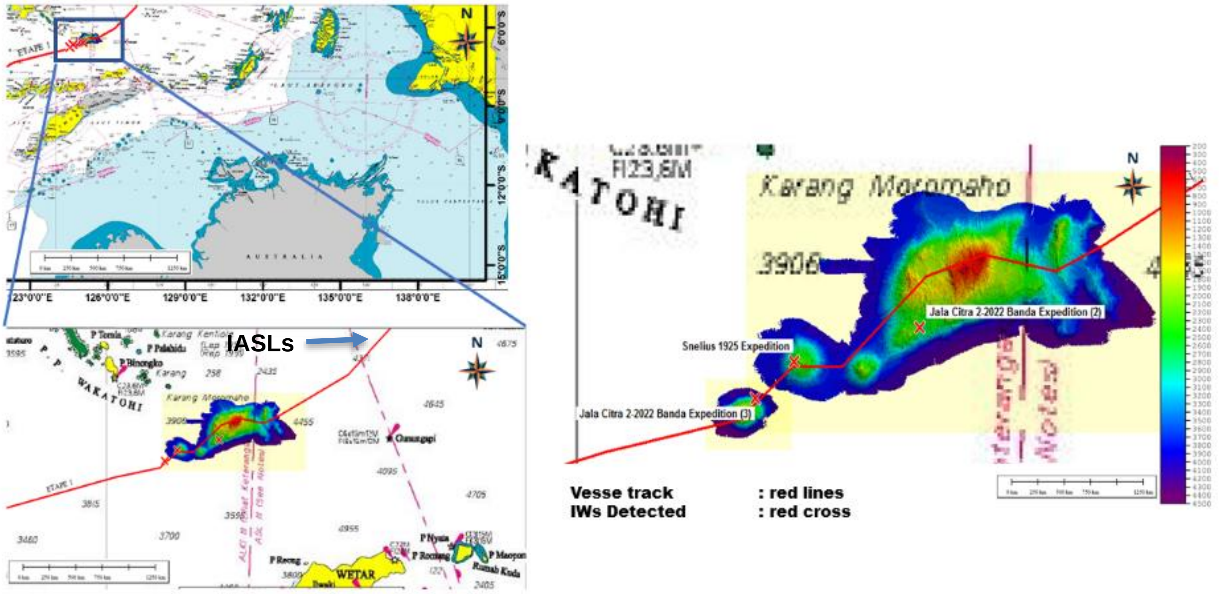

Figure 8. 1925 Snellius Expedition "turbulent water" at a position of 6°40' S and 124°41'E and ISWs packet detected by *Single Beam Echosounder* EA600 50 kHz during Jala Citra Expedition on July,14 2022 at a position of 6.6° S -125.1° E; on July,15 2022 at a position 6.8° S - 124.5° E in US Nieuwerkerk around the the IASLs.

as 3rd IASLs of Indonesia. Gordon *et al.* (2019) state that ITF transport pathways are from Maluku Sea (MS), Seram Sea (SS) and Banda Sea (BS), in contrast to van Aken *et al.* (2009) state which states that the ITF transport pathways is also heading west across the Buru Waters (see Figure 9.) to the BS. The IWs discovery around Buru Waters by the Jala Citra Expedition is believed to be an ITF route, apart from the presence of sill with a ~165 m deep (Figure 9C.) trough between Buru Island and Sula Island. The phenomenon of IWs in the eastern route of ITF (MS) has also been observed using the seismic oceanographic method by Firdaus *et al*. (2021). Jala Citra Expedition result show that typical of IWs in Buru Water (Asmoro *et al.*, 2024) is HFNWs with amplitude high ~20 m, physical oceanographic parameters also using MC model data occurred on August 17, 2022 also revealed a wavy pattern (Figure 10.), like with Bali Waters.

The Linkage of internal wave mapping with Indonesia's underwater navigation and Defense

The development of defense areas that are carried out on a spatial basis by empowering geospatial data and information. Maritime geospatial information for defense has been provided in the form of multiple layers of paper or modified charts over the years. With the move to digital products, the Additional Military Layer (AML) has been designed to provide this maritime geospatial information to defense users in an efficient and standardized digital format and can directly update data based on the novelty of geospatial information data and rapid intelligence analysis (Mahendro *et al.,* 2020). The AML Handbook of NATO (2016), requires AML maps to at least contain geospatial information regarding: Contour Line Bathymetry (CLB); Environment, Seabed and Beach (ESB); Large Bottom Objects (LBO); Maritime Foundation and Facilities (MFF); Small Bottom Objects (SBO); Routes, Areas and Limits (RAL) (Asryanto *et al.*, 2022); Integrated Water Column (IWC); Atmospheric and Meteorological Climatology (AMC); Network Model Bathymetry (NMB); and Gridded Sediment – Environment, Seabed and Beach (GS-ESB). AML includes all aspects of data and information needed to support the implementation of military operations at sea, whether carried out by surface ships, submarines or anti-submarine warfare (Hadi *et al.,* 2016; Armansyah *et al.,* 2019). At least the results of the Jala Citra Expedition 2-2022 "Banda" on occasion can be used to update the AML database at CLB points; LBO and GS-ESB (US Nieuwerkerk which can still be searched based on the backscatter value) and IWC (detected IWs from SBES). Besides that, knowing the initial source of IW propagation and periodic time in the IS (in this case from the Ombai and Lombok Strait) can be used as a benchmark in determining or planning of tactical oceanographic surveys; timing and training methods; and underwater navigation routes, especially in submarine maneuvers so that the KRI Nanggala 402 tragedy does not repeat itself in the future, where the damage to the main weapons system equipment (defense equipment) can directly impact Indonesia`s underwater defense.

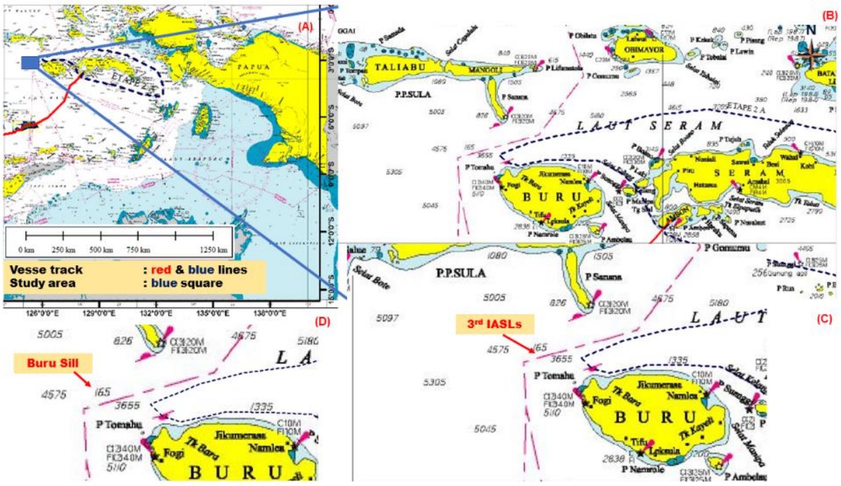

Figure 9. Study area of Buru Water (a); 1st etape and 2And etape vessel track during Jala Citra Expedition 2-2022 "Banda" (b); 3rd IASLs of Indonesia (c); and Buru Sill (d)

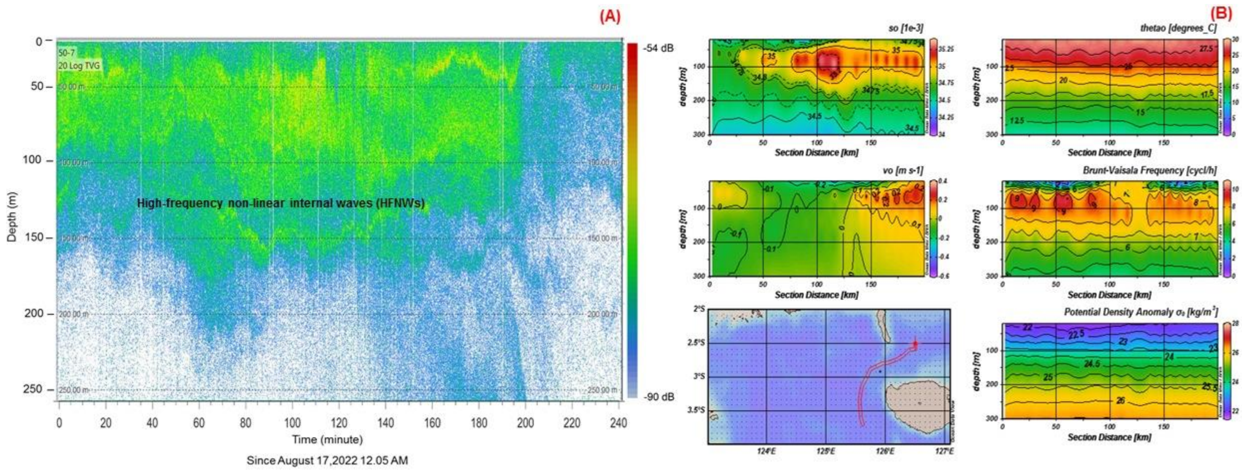

Figure 10. IWs detected by *Single Beam Echosounde*r EA600 50 kHz result from Jala Citra Expedition on August,17 2022 at a position 3.5° S - 125.5° E in Buru Waters (a) and physical oceanographic from MC model data on Jala Citra Expedition vessel track on August,17 2022 around Buru Waters (b)

Conclusion

The Jala Citra Expedition 2-2022 "Banda" on this occasion was able to reveal the phenomenon of "turbulent water" as stated in the 1925 Snellius Expedition report, where the phenomenon is alleged to be an ISW package originating from the Ombai Strait which propagates as far as ~180 km. IWs emit radiation (rays) from the topography and the interaction between barotropic tidal currents during the spring tide. Typical internal waves in IS consist of ISWs and NHFWs. The topographical slope of the seabed plays a role in the distribution of IWs. The estimated wave crest amplitude ranges from ~20 m to ~65 m. The results of this expedition are expected to be used as a basis for updating the AML database and determining/planning tactical oceanographic surveys, timing, training methods, and underwater navigation paths, especially in submarine maneuvers with direct implications for strengthening the Indonesian underwater defense system as outlined in the IWC AML. The detection of IW events by acoustic devices (*e.g.* SBES) is considered effective, which can further be used as a guide for underwater maneuvering and navigation activities in the water column.

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