Extreme Significant Wave Height of Western and Central Indonesian Seas and Its Correlation with ISO 19901-1:2015

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Highlights:

- The SEAFINE-based extreme significant wave height ranges from 4.5 to 5.5 m near the northern part of Natuna island for a 1-year return period and is approximately doubled for a 100-year return period.
- In the Indonesian inner seas such as the Java Sea, the significant wave height ranges from 0.5 to 2.5 m for a 1-year return period and 1.5 to 5.0 m for a 100-year return period.
- The SEAFINE-based 1-year and 100-year extreme significant wave heights are approximately 25% lower than that from ISO in intersecting regions.

Abstract. Extreme significant wave height is a commonly used parameter for designing offshore structures. ISO provides general extreme significant wave height information of six ocean regions in the world, including the Southern East Asian Sea. However, for the case of Indonesia, ISO only includes the Natuna Sea region. One of the qualified datasets that provide significant wave height data for Indonesian seas is SEAFINE by Oceanweather, Inc. This dataset covers the western and middle parts of Indonesia. We analyzed the SEAFINE significant wave height hindcast data in these regions to obtain its extreme values. Extreme significant wave height maps were then produced based on the analyzed data. For validation, we compared the extreme value analysis result with ISO 19901-1:2015 in regions where SEAFINE and ISO data intersect. The comparison showed that the analysis result tends to give approximately 25% lower wave height compared to the ISO for the 1-year return period. The 100-year return period, however, highly agrees with the ISO. The analysis result also shows in line with previous studies in the Karimata Strait and the Java Sea.

Keywords: *Asia; ISO; metocean; SEAFINE; significant wave height.*

1 Introduction

Indonesia has 6.4 million km^2 of water area, accounting for about 77% of the total Indonesia area [1]. This relatively large water area has many potentials, such as maritime transportation, fisheries, ocean energy, mineral resources, and tourism

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[2]. The Government of Indonesia has stated that Indonesia has 15,000 trillion Rupiah or about 1 trillion USD of annual ocean economic potential [3].

To fully utilize its ocean potential it is important for Indonesia to thoroughly study relevant ocean parameters. One of the most widely used ocean parameters is significant wave height or H_s. H_s was introduced by Sverdrup and Munk [4] as the average wave height of the 33% highest recorded waves. H_s is also used in recent coastal erosion studies, since higher waves tend to erode the coastline more [5]. H_s information is also valuable for sailors since higher waves can cause problems in ship navigation [6]. The latest studies about ocean energy also incorporated H_s to show the wave energy potential in an area [7]. Offshore operations such as underwater pipeline laying can be unsafe due to high waves generating high stresses.

More specific use of H_s is apparent in the design of offshore structures such as oil and gas extraction facilities. According to the Indonesian Special Work Unit for Oil and Natural Gas Upstream Business (SKK Migas), there are 612 offshore platforms in Indonesia, of which 587 are operational [8]. These platforms are concentrated around Natuna island, Malacca Strait, Madura Offshore, Papua Offshore, and other regions, as shown in Figure 1.

Figure 1 Distribution of offshore platforms in Indonesia including operational, not operational, and ready to be abandoned platforms. (Source: SKK Migas [8])

Extreme H_s is a critical parameter for designing the structural members of offshore structures along with significant wave period and directionality.

According to the American Petroleum Institute [9] and Det Norske Veritas [10], the structural analysis of offshore steel structures used 1-year and a 100-year return period H_s. These extreme H_s parameters are used for analysis in operating conditions and storm conditions respectively.

There are several previous studies regarding H_s in Indonesian ocean regions. Badan Meteorologi, Klimatologi dan Geofisika (Meteorological, Climatological, and Geophysical Agency of Indonesia) collects H_s daily [11] but does not provide an extreme H_s distribution map. The study by Firdaus, *et al*. in 2011 refers to Djatmiko, *et al*. [12], which shows the potential locations for wave energy extraction, classified as areas with H_s more than 2 m and a wave period of 9.5 s. This study showed that the potential areas are concentrated in the Natuna Sea, the southern part of Indonesia, the Aru Sea, the Banda Sea, and north of Papua island. Kurniawan & Khotimah [13] presented mean H_s in seasonal periods along with the probability of H_s exceeding 2 m.

However, studies regarding extreme H_s in the Indonesian seas are limited. One of the internationally recognized standards that present this parameter is ISO 19901-1 by the International Standards Organization [14]. ISO 19901-1 contains information on 1-year and 100-year return period H_s in East Asian Sea regions in its 2015 release. It is mentioned in ISO 19901-1 that the sources of the wave data include satellite altimeter measurements, commercial organizations, and SEAMOS (South East Asia Meteorological and Oceanographic Study) hindcast wave data. SEAMOS includes hindcast wave data from 1946 to 1996. SEAMOS has a 25 km grid covering the whole East Asian Sea. Although the data are not continuous, it covers 246 large monsoons and typhoons within the database period [14].

However, in the case of Indonesia, ISO 19901-1 only covers the Natuna Sea region in the north-western part of Indonesia. Extreme H_s maps of Indonesian seas have the potential to support the development and operation of Indonesian offshore platforms. Long-term wave data are required to create such H_s maps. Suitable data are available from SEAFINE (SEAMOS-South Fine Grid Hindcast) by Oceanweather, Inc. Joint Industry Project [15]. One disadvantage of the SEAFINE data is that they only cover the western and central inter-island seas of Indonesia. Nevertheless, the usability of these maps is still high since most offshore platforms in Indonesia are located within this area.

The current study aimed to create 1-year and 100-year return period H_s maps of the Indonesian western and central seas based on the SEAFINE database. These maps were then compared to ISO's extreme H_s. This standard was chosen as it is one of the internationally recognized standards for extreme H_s in the South East

Asia region. The created maps were also compared with the results of other previous Indonesian wave climate studies.

This paper is organized as follows. The background and motivation of the study are described in Section 1. The utilized methodology and data are explained in Section 2. The EVA (Extreme Value Analysis) results to obtain extreme H_s maps based on the SEAFINE data points are presented in Section 3. The extreme H_s map is discussed and compared with the results from previous studies in Section 4. Finally, the study is concluded in Section 5.

2 Methodology

The general methodology of this study is shown in Figure 2. The first step was to extract the H_s data from each data point in the SEAFINE database. The annual maximum H_s values were then obtained for each data point. EVA was then performed based on the annual maximum H_s values to obtain the 1-year and the 100-year return period H_s value for each data point. These extreme H_s values were then plotted onto a map and compared to the ISO data as well as other relevant past studies.

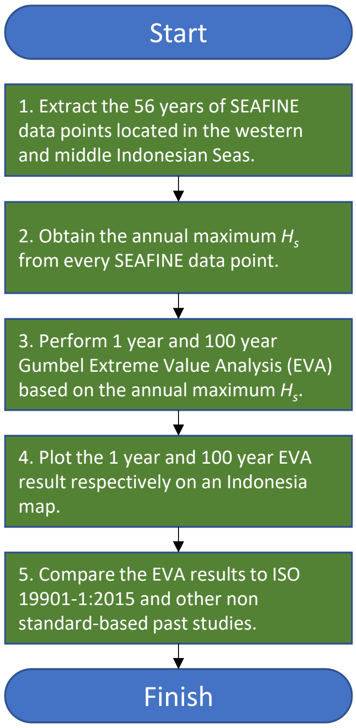

Figure 2 General methodology of SEAFINE EVA of this study.

Several previous studies have compared SEAFINE data with other widely available sources. The study by Mayeetae, *et al*. [16] showed that the SEAFINE hindcast data have a strong correlation with measured buoy data in the Sarawak Basin, Malaysia. However, the study also showed that the SEAFINE data often missed extreme wind speeds over short periods. Muliati, *et al*. [17] compared SEAFINE, ECMWF (European Center for Medium-Range Weather Forecasts)'s ERA-Interim, and SWAN (Simulating Waves Nearshore) data for the Natuna Sea. They found that the SEAFINE data tended to give about 30% higher H_s estimates compared to ERA-Interim and 45% higher compared to the SWAN simulation conducted in the study. Based on these reports, it can be concluded that SEAFINE is a reliable dataset to be used for metocean studies, with a tendency to overestimate other hindcast models.

The SEAFINE dataset is available in 25-km and 6-km spacing resolutions. Since the 6-km spaced dataset is only available for the South China Sea, Madura Offshore, and Makassar Strait, this study used the 25-km spaced dataset. Seas covered by the 25-km include Offshore Natuna island, the Java Sea, the Flores Sea (partially), the Banda Sea, the Sulawesi Sea, and the South China Sea. However, to reduce the computational requirements, this study picked one data for every 50 km from the 25-km dataset, with the positions as shown in Figure 3.

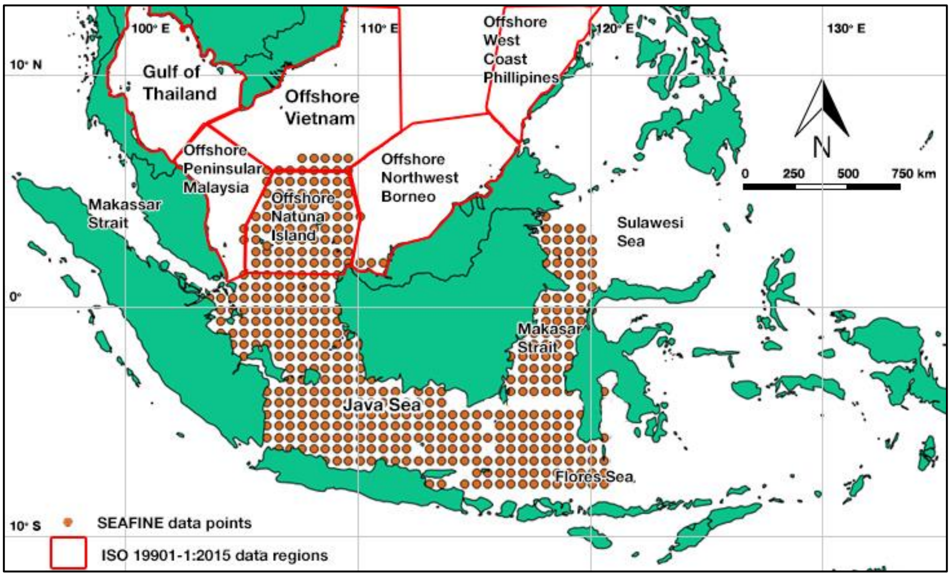

Figure 3 Significant wave height data points from SEAFINE 25-km spaced data and ISO 19901-1 data regions.
Source (sata regions) : International Standards Organization [14]
Source (data points) : Oceanweather, Inc. [15]

Data included in the SEAFINE dataset are hourly time series of ocean wind and wave parameters. The wave parameters include (1) wave spectrum variance, (2) spectral period, (3) spectral moment, (4) dominant direction, (5) wave spreading, and (5) significant wave height. This study only used the significant wave height data from the SEAFINE dataset. The available wave data ranged from the year 1956 to 2015 in an hourly resolution. The data regions in the ISO intersect with SEAFINE mostly in the Offshore Natuna island region and partially in the Offshore Peninsular Malaysia, Offshore Vietnam, and Offshore Northwest Borneo.

The SEAFINE data for each point were extracted using the bundled OSMOSIS software from Oceanweather, Inc. [15]. Since the extracted data are hourly data, the H_s extreme value for each data point must be obtained using the EVA method to match the ISO wave parameters. This study used the Gumbel distribution method to obtain extreme values from each data point. Gumbel is one of the standard distribution methods for EVA for offshore metocean data by ISO [14] and DNV [18]. The equation for the Gumbel distribution is as follows:

$$X_p = \bar{X} + (S_x \times K) \tag{1}$$

where:

X_p = the expected value for a certain return period (m)
$\bar{X}$ = average of data X (m)
S_x = standard deviation of data X
$= \left(\frac{\sum_{i=1}^{N}(X_i - \bar{X})^2}{N-1}\right)^{0,5}$
N = number of data within data X
K = frequency factor for the Gumbel distribution

3 Result

The EVA result for 1-year and 100-year H_s respectively were plotted onto the map of Indonesia as shown in Figure 4. For the 1-year return period EVA, the H_s was 4.5 to 5.5 m at the northern part of Natuna island. H_s gets lower, in the range of 0.5 to 2.5 m, starting from the Karimata Strait up to the Flores Sea. The 100-year EVA H_s map shows a more contrasted difference. The northern side of the North Natuna Sea has the highest H_s at 8.0 to 8.5 m. The H_s decreases as the data points enter the South Natuna Sea, ranging from 3.5 to 6.0 m. This reduction goes further, ranging from 1.5 to 5.0 m in the Java Sea, the Flores Sea, and the Makassar Strait.

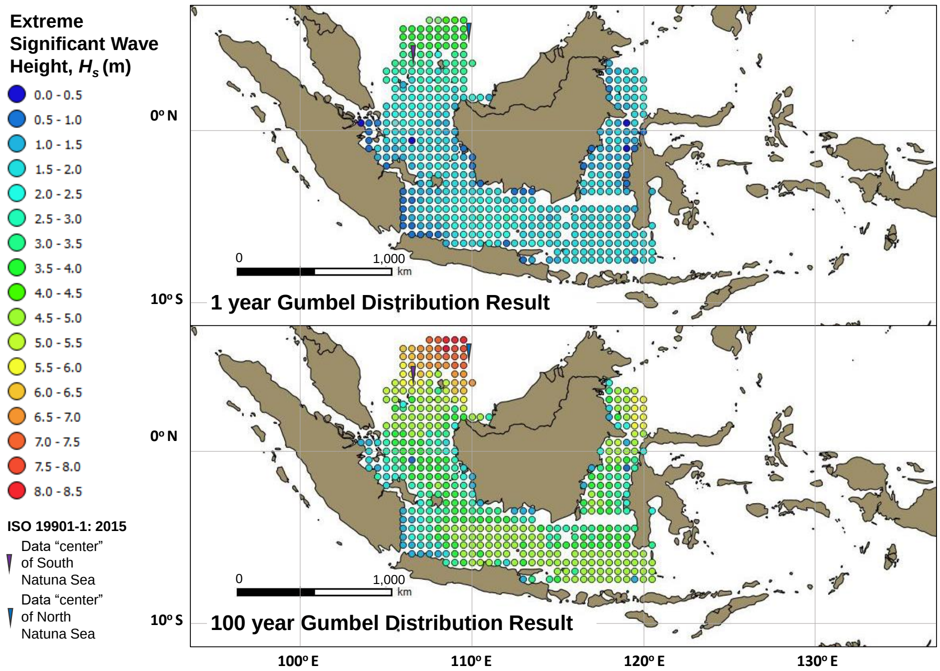

Figure 4 Result of 1-year and 100-year extreme H_S analysis of SEAFINE data using the Gumbel distribution method.

In both return periods, H_S is consistently lower in coastal areas that are not directly exposed to the South China Sea. The H_S in areas such as the east coast of Sumatra, the north coast of West Java, and southwest to the south coast of Kalimantan have H_S values between 0.5 m to 1.5 m in 1-year EVA and 1.0 meter to 2.5 m in the 100-year EVA.

4 Discussion and Analysis

According to ISO, the 1-year H_S values at the data centers shown in Figure 4 are 5.1 m in the South Natuna Sea and 5.8 m in the North Natuna Sea. The data center coordinates are 3.5° N, 106°E for the South Natuna Sea and 5°N, 110° E for the North Natuna Sea. The ISO values at these data centers are approximately 2 m higher than the 1-year SEAFINE EVA results in points surrounding the data centers.

However, the difference between the ISO data and the analysis result is very small for the 100-year return period. The ISO data show that the 100-year H_S values are 5.8 m and 8.0 m in the South Natuna Sea and the North Natuna Sea respectively. The South Natuna Sea ISO value is only approximately 1 m higher than the analysis result. The difference is even smaller in the North Natuna Sea, where the analysis result is less than 0.5 m lower than the ISO value. A graphical comparison of SEAFINE EVA and ISO is shown in Figure 5.

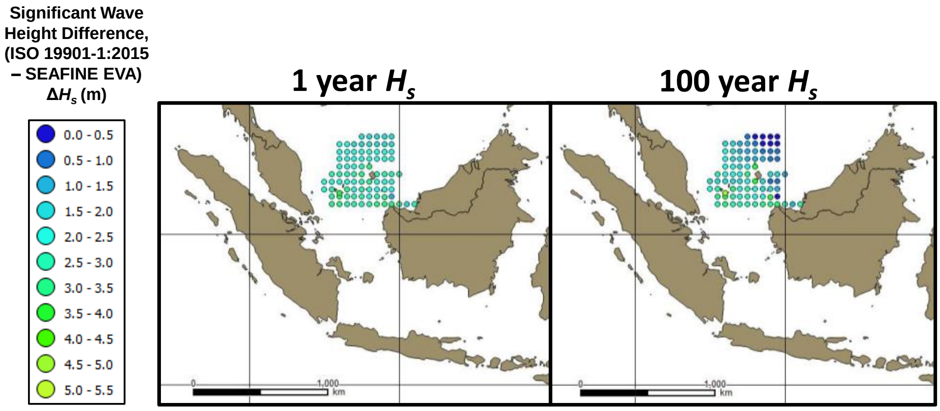

Figure 5 Significant wave height difference between ISO-19901-1:2015 and SEAFINE EVA.

SEAMOS's characteristics are less likely to be the reason for SEAFINE's extreme H_s underestimation. SEAMOS dataset models major typhoons and monsoons in the East Asian Sea from 1946 to 1996 at a 1-hourly interval. However, smaller storms throughout this period are not modeled and may affect the EVA process in obtaining 1-year and 100-year H_s values from ISO-19901-1. If ISO only used SEAMOS for the extreme wave height, the H_s is expected to be lower than in SEAFINE. SEAFINE itself was designed to alleviate the problem caused by the exclusion of smaller storms by continuously hindcasting wind and wave conditions at an hourly interval for 50 years.

A possible explanation for the H_s underestimation is that ISO may also use data for EVA from satellite altimeter measurements and commercial organizations besides SEAMOS. These other data are mentioned in the document, although there is no clear explanation of which data were used for obtaining the extreme H_s values. This may have resulted in higher or lower extreme H_s values in ISO 19901-1:2015. Another possible reason is that the extreme values are factored for safer designs because ISO 19901-1:2015 is used for design purposes.

SEAFINE's underestimation is also likely caused by the low wind data resolution. SEAFINE is a hindcast model that utilizes wind as a force that generates waves. A study by Stopa and Cheung [19] compared two databases, i.e. ERA-Interim by the European Center for Medium-Range Weather Forecasts (ECMWF) and CFSR by National Centers for Environmental Predictions

(NCEP). Both databases use the hindcast method to generate wave data. The main difference between these two databases is in the wave generation. The CFSR has a 0.5-degree grid for surface wind resolution while ERA-Interim has a 79-km grid, which is approximately 0.7 degrees. The result shows that the CFSR has an overall higher estimate of H_s and a lower error when compared to field measurements. However, in general, both databases overestimate the small wind and wave measurements while underestimating the larger ones. This potentially makes the EVA process underestimate ISO 19901-1:2015 since the difference between lower and higher waves is smaller compared to field measurements.

In the inner seas of Indonesia, the SEAFINE EVA result is generally in line with previous studies. The study by Al-Farisi & Zikra [20] presents data used for the structural analysis of an offshore platform in Arjuna Field, which is at the north of West Java (5o 54' 53.0" S, 107o 43' 51.0" E). In their study, the 1-year and 100-year maximum wave heights were respectively 5.00 m and 8.32 m. According to Goda [21], the maximum wave height for the design of an offshore structure should be twice H_s or more. Therefore, the 1-year and 100-year H_s values in this location should be below 2.50 m and 4.16 m respectively. These values are in line with the EVA result from this study for that location, which is in the 1.0 to 1.5 m range for a 1-year return period and in the 1.5 to 2.0 m range for a 100-year return period.

Other studies found a close agreement with the SEAFINE EVA result. The study by Wicaksana, *et al*. [22] used the monthly average wind speed obtained from NCEP Reanalysis Data from NOAA (National Oceanic and Atmospheric Administration) in the Karimata Strait and the Java Sea to model H_s in these areas. The modeling result showed that between 2005 and 2013, the monthly H_s ranged from 0.5 m to 3.0 m. These wave characteristics agree with the analysis result from this study, where the wave height pattern in the two locations is similar. Moreover, the 1-year H_s in the Karimata Strait and the Java Sea peaked at 3.0 m, which agrees with the findings by Wicaksana *et al*. [22]. However, since no long-term observation data are available for the Indonesian seas, it is difficult to validate the modeling result. The BPPT report shows that out of 12 buoys from the 1st Generation Indonesia Tsunami Buoy Development Program, 4 were vandalized and 3 had their operation ended in 2009 [23]. It was later also reported in 2018 by BNPB that all Indonesian tsunami detection buoys were broken since 2012 [24].

5 Conclusion

Extreme H_s maps of western and middle Indonesian seas have been created and compared with ISO 19901-1:2015. It was found that the SEAFINE EVA H_s result is approximately 25% lower than ISO 19901-1:2015 for a 1-year return period in the intersecting hindcast region. However, the 100-year EVA of SEAFINE was close to that from ISO 19901-1:2015 for the same area. The difference between the SEAFINE EVA results with previous studies varies for Indonesian inner seas, such as the Karimata Strait, the Java Sea, and the Flores Sea. In general, SEAFINE agrees well with other previous studies, with a tendency to predict slightly lower H_s values.

The extreme H_s maps developed in this study have the potential to be used nationwide for various purposes, especially in the oil and gas industry. For future studies, we suggest validating the analysis result with the EVA of long-term regional numerical modeling. It is also recommended to compare the EVA result with offshore platform assessment data from past industrial projects, which usually incorporate extreme H_s data.

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Nomenclature

H_s	=	Significant wave height
EVA	=	Extreme value analysis
ISO	=	International Standard Organization
NOAA	=	National Oceanic and Atmospheric Administration
ROV	=	Remotely operated vehicle
SWAN	=	Simulating Waves Nearshore model

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