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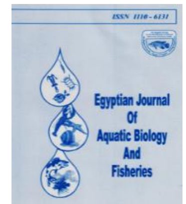

Evaluating the Accuracy of ERA5 Wave Reanalysis with *In Situ* Data on the Egyptian Mediterranean Coasts

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ABSTRACT

Wave is an effective physical oceanographic parameter essential for human maritime activities, such as ships' navigation, coastal engineering and sediment transportation. Hourly wave data records were acquired from four buoys, deployed in different locations: Alexandria Western Harbor, Alexandria Eastern Harbor, Port Said Harbor, and Rashid site along the southeastern coast of Egypt, utilized for validating waves 'hourly data, obtained from the European Centre for Medium-Range Weather Forecasting Reanalysis. Results revealed that the mean direction of waves using wind rose analysis is north-west-north for all offshore deep-water buoys in both datasets. In contrast, the results from onshore shallow-water buoys in AWH were in a different direction, with a weak correlation value (0.04). Furthermore, the differences in mean significant wave height of offshore buoys ranged from −0.17- 0.14m, respectively, and correlation values were 0.88, 0.96 and 0.96. Meanwhile, the differences in the same data SWH from onshore buoys fluctuated between 2.9 and 2.96m, with a correlation value of 0.73. In addition, the root-mean-square error in SWH ranges between 0.001 and 0.126m. Moreover, the standard deviation does not exceed 0.89m and is even as low as 0.16m at all far sites. While, in the near coast locations, it reaches up to 1.53m. Accordingly, the mean zero-crossing period correlation between the two datasets was 0.14, 0.91, and 0.89, while in the near coast buoy, it was 0.069. Meanwhile, the bias in mean zero-crossing period between both datasets (ERA-5 and buoy) showed a difference in the mean ranges from 0.08 s to 1.6 s. Finally, from the analysis of the three main wave parameters, the validity of ERA5 wave data was confirmed, except for the shallow nearshore areas as well as the low-depth sensor due to its low accuracy.

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INTRODUCTION

Wave data are important for many aspects, such as marine resource development, engineering construction, shipping, cross-border trade and scientific research. Extreme dynamic processes such as huge waves may cause damage to infrastructure or shorelines **(Wu *et al.*, 2021; Niu *et al.*, 2021)**. Human activities such as maritime trade, oceanographic engineering design, ship design, and hazard mitigation are all affected by waves and wind. The height and crest of waves are the essential wave characteristics for engineering applications **(ISSC, 2015)**. Maritime commerce, oceanographic engineering, and other fields require datasets with suitable duration and precision. Several techniques, including the employment of voluntary observing ships, synthetic aperture radar, satellite altimetry and the use of buoys and lasers can be used to gather these data. Ship data have the longest history of these observation data; nevertheless, their quality fluctuates and may miss extreme events due to shipping patterns **(Gulev *et al*., 2003)**. Light vessels and buoys can provide a wide range of measurements and valuable information **(Bromirski *et al*., 2005; Genmrich *et al*., 2011)**. However, they are limited to discrete locations **(Stopa & Cheung, 2014)**. Satellite altimetry can cover a huge area of the ocean with extreme accuracy. As a result, it has been recognized as a valuable resource in the field of climate research **(Hemer *et al*., 2010)**. However, the orbit of satellites is periodic for the fixed field, varying from 10 days to 35 days, and satellite altimetry temporal resolution is weak, making predicting long-term distributions and exceptional events problematic **(Kumar & Naseef, 2015)**. Compared to historically collected data, hind casts have become more popular in the recent decade for design and are constantly being developed and improved. The ERA-Interim (ERA-I) dataset is a subset of the ERA dataset (Dee *et al*., 2011) and is available for all locations worldwide from 1979 to the present. ERA5 **(Hersbach *et al*., 2016)**, the ECMWF's most recent reanalysis output, which includes data from 1979 to the present, is the most up-to-date. Coupled atmosphere-wave models generate both wind and wave datasets. For climate studies and commercial activity, archival operational forecasts have been a valuable source of wind and wave data **(Agarwal *et al*., 2013; Shanas & Kumar, 2014)**. The European Center for Medium-Term Weather Forecasting (ECMWF) is one of the world's prominent reanalysis centers. It broadcasts the latest (fifth) generation reanalysis dataset (ERA5). The dataset offers comprehensive worldwide coverage of wave parameters **(Hersbach *et al*., 2018; ECMWF, 2022)**. Datasets are inadequate for analyzing multiyear climate signals since model physics, resolution and assimilation methodologies are constantly being changed. As a result, the focus should be shifted to ocean wave climate modeling **(Reguero *et al*., 2012; Rascle & Ardhuin, 2013)**. There are numerous reanalysis datasets available, and various models are employed. The accurate evaluation of hindcasts is an important step in improving wave models and subsequently operational forecasts **(Cavaleri *et al*., 2012)**. Several researches such as that of Caires *et al*. (2004) was conducted to accomplish this work. Using altimeter and buoy data, researchers analyzed the wind speed and significant wave height (SWH) data from multiple reanalysis datasets. They concluded that, while the dataset quality varies from that of the observed data, most long-scale features are largely consistent across all datasets. There are many comparative studies of the parameters of the ocean specified in the ERA5 model with measurement data have already been carried out by several researchers. It is shown by their results that, on average, the ERA5 database can be efficiently used in scientific research, despite significant differences in hourly data, probably due to the scarcity of long-term observation data (Shi *et al*., 2021).

Egyptian northern coastal zones are crucial from an economic perspective, as they serve as a major commercial route for exports and imports of global products (Encyclopedia Britannica, 2017). Furthermore, they serve numerous industrial activities, such as oil and gas, in addition to chemical companies. Various densely populated economic cities, including Alexandria, Rashid, Damietta, and Port Said, are the epicenter of those activities (El Raey, 2010). Extreme climatic phenomena such as storm surges, combined with human-induced pressures, have made the Mediterranean coast of Egypt into a succession plague (Satta *et al*., 2017).

The Mediterranean coast of Egypt is always beset by issues such as rapid population expansion, land subsidence, saltwater intrusion, unplanned urbanization, high rates of erosion, interference with land usage, soil salinization, and contamination and destruction of ecosystems (Darwish *et al*., 2013). Besides domestic effluent, industrial wastewater, agricultural drainage, and petroleum products are all discharged into the water on the coast in front of Alexandria.

Consequently, as a result of such reasons predicting the transit of such pollutants becomes very critical. (Alam El-Din,2007) analyze and studied wave data acquired during the Alexandria wastewater project's second phase from 1996 to 1997 studied the mean significant wave height (Hs) was 0.74 m, with a maximum Hs of 2.85 m, and the primary wave directions were NW and WNW, according to research into the hydro-dynamical characteristics influencing transport processes in the Alexandria coastal area.

The Earth observation program run by the European Union (EU) is called Copernicus. It provides information services based on in-situ (non-space) data and satellite Earth observation. The EU Agencies, Mercator Ocean, the Member States, the European Space Agency (ESA), the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), the European Centre for Medium-Range Weather Forecasts (ECMWF), and the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) are all partners in its implementation. (Copernicus,2022), (accessed in October 2022).

ECMWF (European Centre for Medium-Range Weather Forecasts) produced ERA5 the fifth generation of atmospheric reanalysis of the global climate. ERA5 has a horizontal spatial resolution of 31 km and 137 vertical levels ranging from the surface to

80 km (0.01 hectare). Furthermore, by early 2019, ERA5 data covering the period 1950 to the present will be accessible for usage (ERA5; https://www.ecmwf.int).

Mohamed and. Sanil (2019) in the Indian Ocean (IO) during 1979–2017 he ERA5 significant wave height (Hs) and maximum wave height (Hmax) show a good agreement with measured buoy data in the coastal (bias 0.29 m) and deep waters (bias 0.18 m), the ERA5 significant wave height (Hs) and maximum wave height (Hmax) exhibit good agreement with measured buoy data. The underestimating of Hs and Hmax in the ERA5 data compared to buoy data is 2.7 and 1.4 % during tropical cyclones, respectively, although the bias is large (0.69 m) in general.

Liliana (2020) Depending on the wave parameters provided by ERA5 in several reference points defined in each basin, the wave power potential in three semi-enclosed European seas, namely the Mediterranean Sea, Black Sea, and Baltic Sea, is evaluated, the period from 1989 to 2018.find that in most of the reference points studied in all of the basins, there is a significant seasonal variability. M1 and M10, the Mediterranean Sea's westernmost and easternmost points, respectively, have certain exceptions. The monthly variability of the points along the Baltic Sea's eastern coast is also lower than that of the other sites.

Maria *et al*. (2020) analyze wave gathered data during a coastal experimental campaign off the coast of southern Oman in the Western Arabian Sea. The results show that the ERA5 wave model overestimates swell wave heights across the studied time period, whereas the height forecast of wind waves is strongly influenced by wave development conditions.

In 2020 Hersbach *et al*. comparing the independent buoy data, the match for ocean wave height is significantly better. The uncertainty estimate is based on the evolution of the ERA5 observation systems.

The study area lies along the Mediterranean Coast in front of Alexandria (western harbor and eastern harbor), Rashid, and Port Said, as shown in Figure 1.

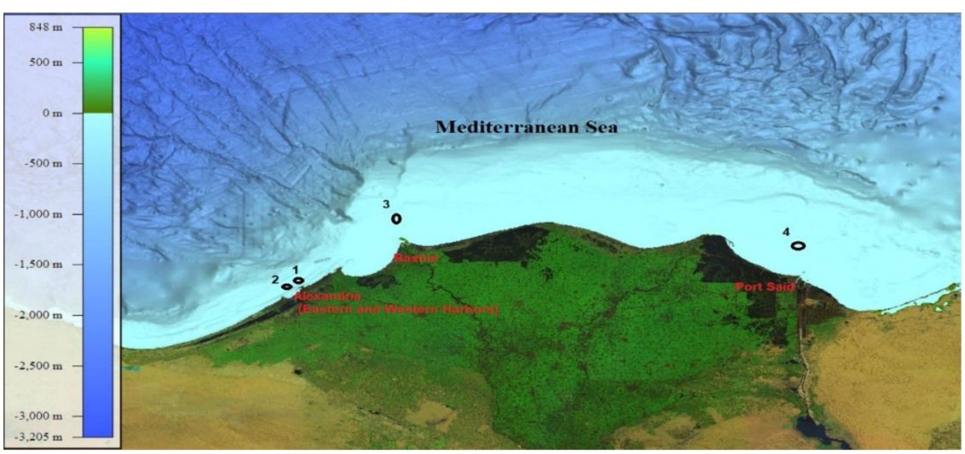


Figure 1: The Egyptian Mediterranean coastal region with elevation (m) by remote sensing (GEBCO_2019).

1 DATA AND METHODS of ANALYSIS

1.1 DATA:

1.1.1 Wave Data from the ERA5 Dataset:

ERA5 is the fifth generation of the European Centre for Medium-Range Weather Forecasts (ECMWF) global climate reanalysis (Dee *et al*., 2011). The ECMWF's most recent reanalysis output is this dataset. The ERA5 reanalysis includes the modern observation period, beginning in 1979 and continuing forward in time with daily updates. ERA5 eventually took the role of ERA-I, which was becoming increasingly difficult to keep up with (Hersbach and Dee, 2016). Hourly analysis fields in ERA5 data have a horizontal resolution of reanalysis 0.25° × 0.25° (atmosphere), 0.5° × 0.5° (ocean waves) mean, spread and members 0.5° × 0.5° (atmosphere), and 1° × 1° (ocean waves). The number of variables presented by ERA5 has risen from 100 in ERA-I to 240, including the coupled-wave model's wave height and direction, allowing users to assess historical atmospheric and oceanic states better.

ERA5 hourly data on single levels from 1979 to present data of mean direction of waves (DIR), the mean zero-crossing wave period of waves (Tz), and the significant height of combined wave (Hs) was obtained from ERA5 on an hourly basis from 1979 to the present with a spatial resolution of 0.25° × 0.25°.

1.1.2 In Situ Wave Measurements:

Buoy wave data obtained from four buoys were used to evaluate the ERA5 datasets. The location of the buoys is shown in Figure 1, and the details of the stations are shown in Table1. Dataset was conducted by the following:

- In front of Eastern Harbor (E.H) were obtained from OSI (Ocean Surveys, Inc.).
- In front of the Western Harbor (W.H) were obtained from Met Ocean (Meteorological and Oceanographic branch, Egyptian Navy Hydrographic Department (ENHD,2008)).

- In front of Port Said and Rashid Fugro Global Environmental and Ocean Sciences (Fugro GEOS) have undertaken a year-long program of Met Ocean measurements around the offshore Nile Delta field between May 1999 and May 2000 for the Belayim Petroleum Company.

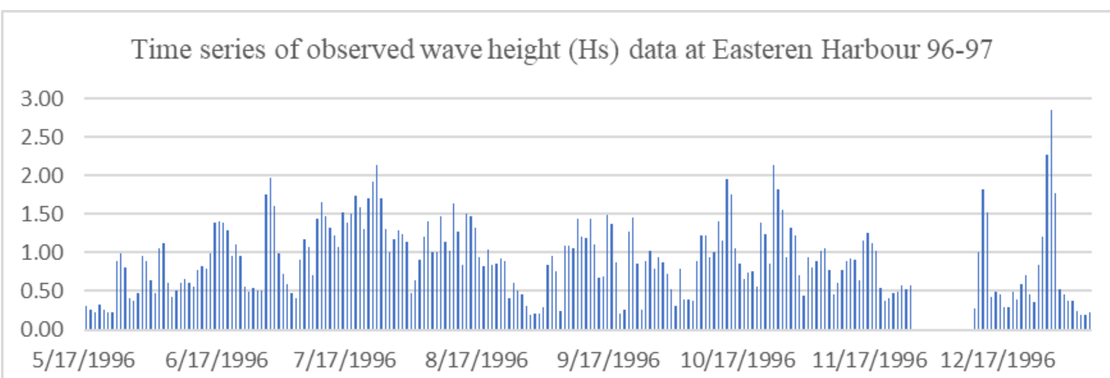
Table 1. Buoys information at different locations.

Location	Position		Instrumen t	Distance	Depth	Period
	Latitude	Longitud e		from land		
Eastern Harbor (E.H)	31°16.25' N	29°51.95' E	Wave gauge	(7.2km)	35 m	5/1996 to1/1997
Western Harbor (W.H)	31°12'N	29°51'E	S4ADW	(1.1 km)	10 m	8/2008 to 10/2008 3/2010 to 8/2010
Rashid Deep (S5)	32°36.54' N	30°21.49' E	Wave rider	(124.2km)	1800 m	1/1999 to 3/ 2000
Port Said Shallow (H1)	31°51'N	32°25.32' E	Directional wave rider	(70 km)	120 m	2/1999 to 9/2000

1.2 Methods of Analysis

1.2.1 Data preparation:

As indicated in Figures 2 and 3, the dataset was categorized and inspected for spikes, outliers, and incorrect data readings before smoothing.



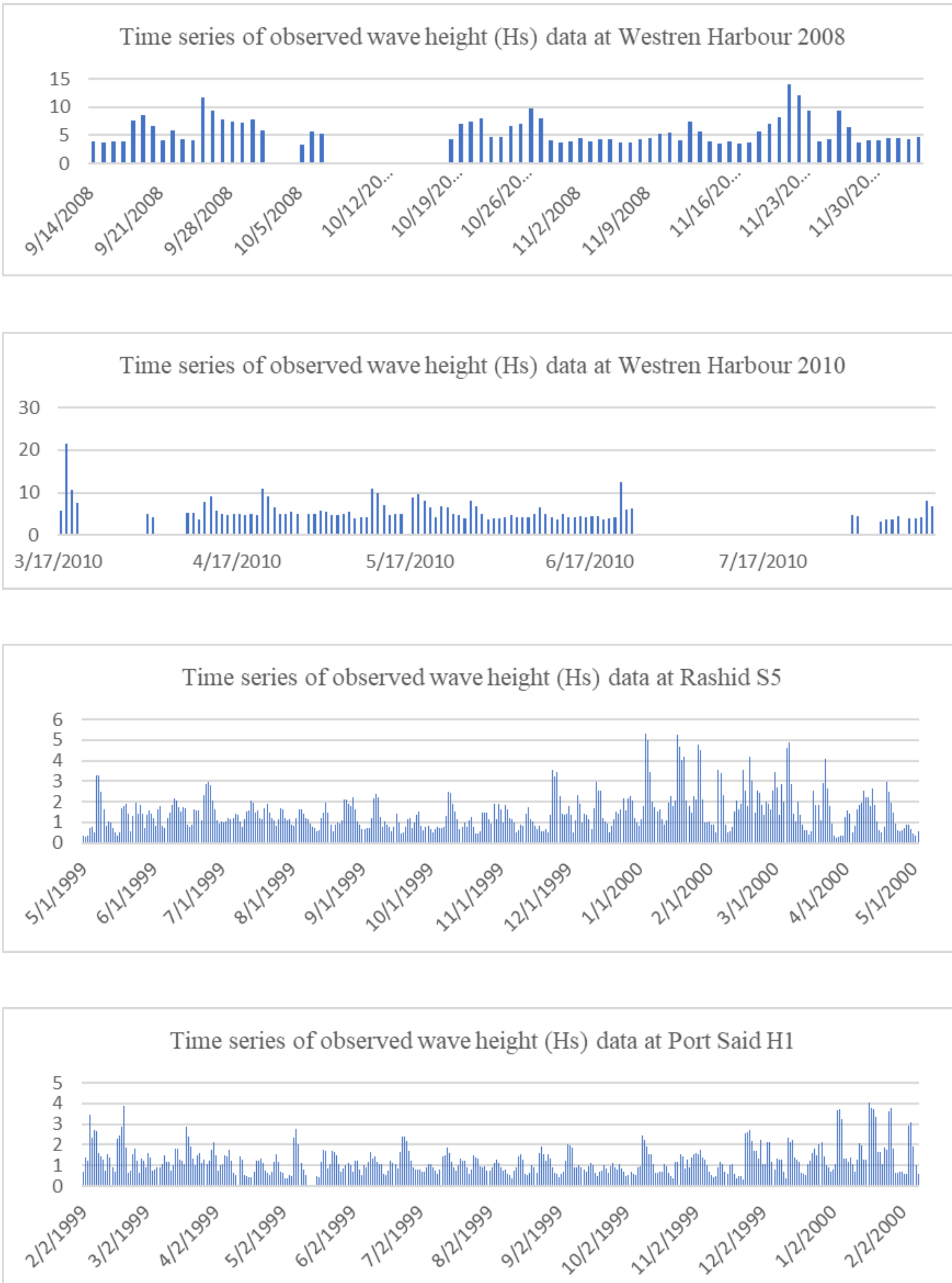
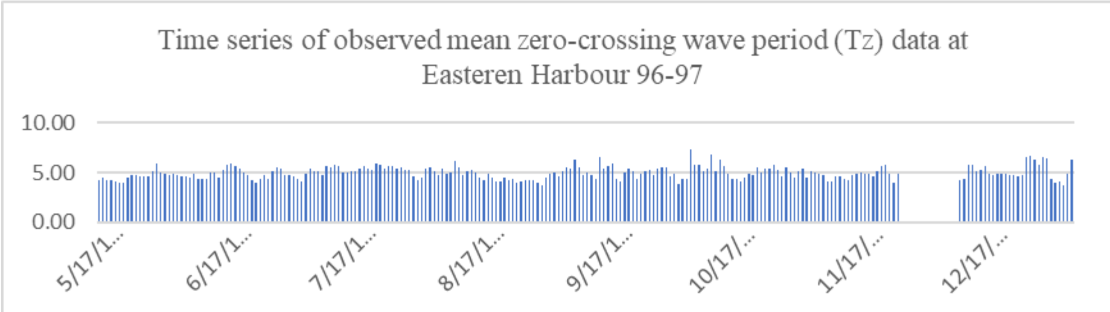
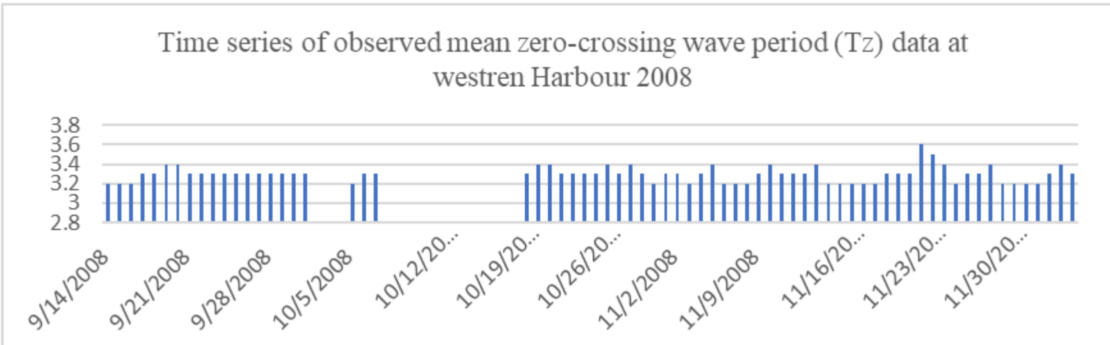
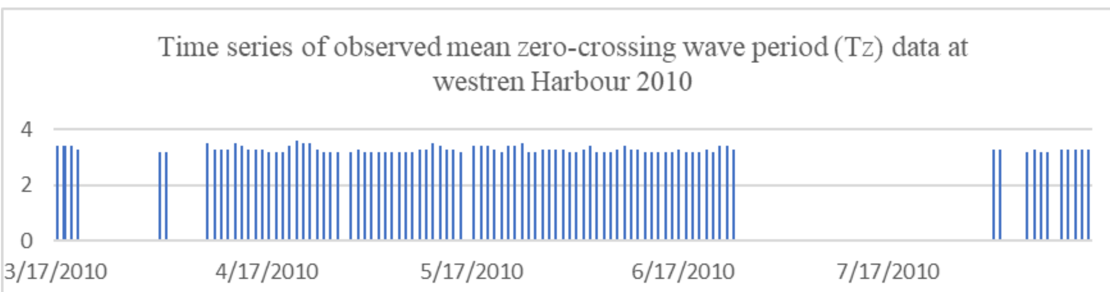
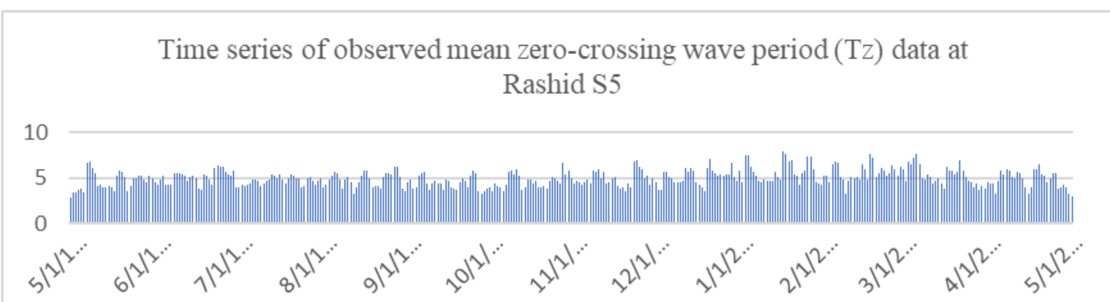


Figure 2 : Smoothed observed wave height data for each data buoy (Missed data due to missed observation).


Time series of observed mean zero-crossing wave period (Tz) data at Easteren Harbour 96-97
10.00
5.00
0.00
5/17/1...
6/17/1...
7/17/1...
8/17/1...
9/17/1...
10/17/...
11/17/...
12/17/...


Time series of observed mean zero-crossing wave period (Tz) data at westren Harbour 2008
3.8
3.6
3.4
3.2
3
2.8
9/14/2008
9/21/2008
9/28/2008
10/5/2008
10/12/20...
10/19/20...
10/26/20...
11/2/2008
11/9/2008
11/16/20...
11/23/20...
11/30/20...


Time series of observed mean zero-crossing wave period (Tz) data at westren Harbour 2010
4
2
0
3/17/2010
4/17/2010
5/17/2010
6/17/2010
7/17/2010


Time series of observed mean zero-crossing wave period (Tz) data at Rashid S5
10
5
0
5/1/1...
6/1/1...
7/1/1...
8/1/1...
9/1/1...
10/1/...
11/1/...
12/1/...
1/1/2...
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4/1/2...
5/1/2...

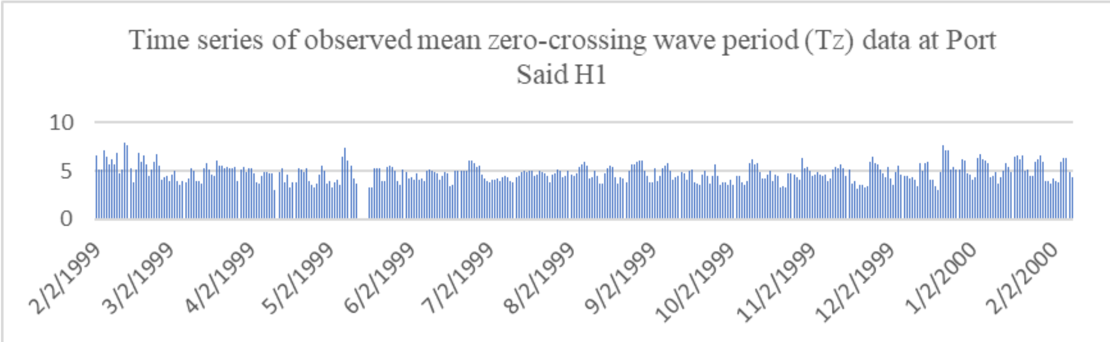


Figure 3: Smoothed observed mean zero-crossing wave period dataset for each data buoy (Missed data due to missed observation).

1.2.2 BIAS

Bias is a numerical term referring to a systematic deviation from the real value. Probability sampling can cause serious problems for the researcher because simply increasing the sample size will not reduce it. Bias is the variation between a parameter's estimated and actual values. Bias can be represented mathematically, as shown in the following equation.

$$\text{Bias} = \frac{\sum_{i=1}^{n}(Oi - Si)}{N} \qquad (1)$$

It is regarded as the term that describes the measurement process's tendency. It analyses the over- or underestimation of the wave height parameter's value.

1.2.3 Root Mean Square Error

Root mean square error is an analytical expression that is very similar to standard deviation (SD) in the sense that RMSE refers to N data points instead of N-1. The following equation can express RMSE.

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{n}(Oi - Si)^2} \qquad (2)$$

Oi is the observed wave height value, Si is the ERA5 wave height value, and N is the number of observed points.

RMSE, considered an evaluation for numerical predictions as a general-purpose error metric, has the same unit of Oi and Si, which can sometimes be expressed in %.

1.2.4 Mean Absolute Error

Mean absolute error (MAE) is another analytical form used along with RMSE in diagnosing the variation in the errors of both data. MAE can be expressed as follows.

$$\mathbf{MAE} = \frac{1}{N}\sum_{i=1}^{n}|Oi - Si| \qquad (3)$$

1.2.5 Scatter Index

The scatter index is computed by dividing the mean of the observations by the root-mean-square deviation (RMSD) or root-mean-square error (RMSE). It displays the percentage of RMS difference concerning the mean observation or the percentage of expected error for the parameter. It is represented mathematically by the following equation.

$$SI = \frac{RMSE}{S^{-}} \qquad (4)$$

The scatter index (SI) is a normalized error measure frequently expressed as a percentage. Lower SI values indicate that the model is performing better. The scatter index, like the RMSE, has ambiguous definitions, with authors either defining it as the standard deviation of the errors divided by the mean of the observations or as the standard deviation of the errors divided by the mean of the observations (Mentaschi et al.,2013; Ris et al.,1999; Rogers et al.,2012; and Akpinar et al., 2012).

1.2.6 Correlation Coefficient

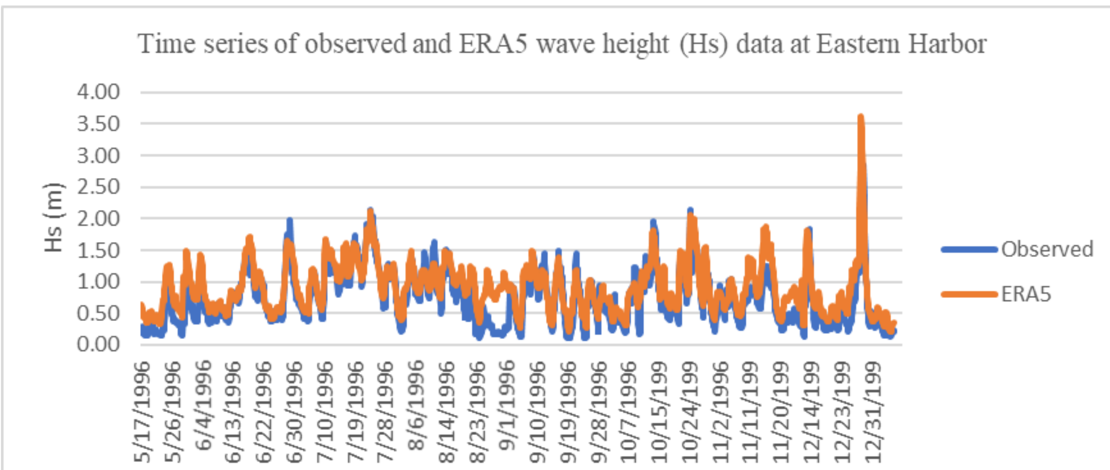
The power of the linear relationship between two variables, x and y, is measured by correlation coefficients. A positive relationship is indicated by a linear correlation coefficient greater than zero. A negative relationship is indicated by a value less than zero. Finally, a zero value indicates that the two variables, x and y, have no relationship; the following equation explains this relationship.

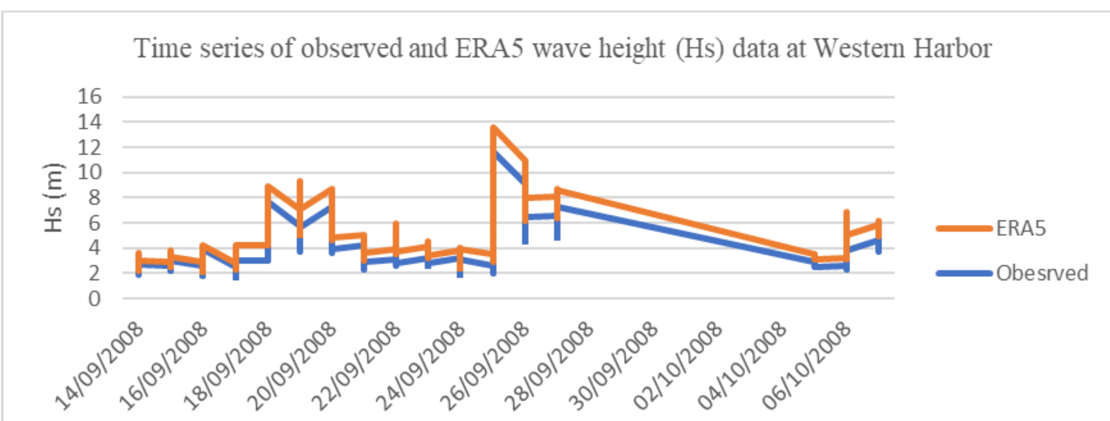
$$COR = \frac{\sum_{i=1}^{n}(Yi - Y^{-})(Xi - X^{-})}{\sqrt{\sum_{i=1}^{n}(Yi - Y^{-})^2}\sqrt{\sum_{i=1}^{n}(Xi - X^{-})^2}} \qquad (5)$$

2 RESULTS

2.1 Significant Wave Height

All data from the missing measurement period was removed from both data in this study. Figure 4 shows the time series of the SWH between ERA5 and the buoy at various positions. The mean SWH in Deep S5 is higher than the mean SWH in Eastern Harbor and Shallow H1 around (SEL); according to to buoy data, the measured buoy data show that the mean SWH in Deep S5 is 1.16, in the Eastern Harbor and Shallow H1, the mean SWH is 0.74 and 0.98. respectively, in the Western Harbor in 2008 and 2010, is3.80 and 3.78, It can be a result of the depth sensor on the buoy (S4ADW) situated at the bottom, taking the depth into account, as shown in Table 2.





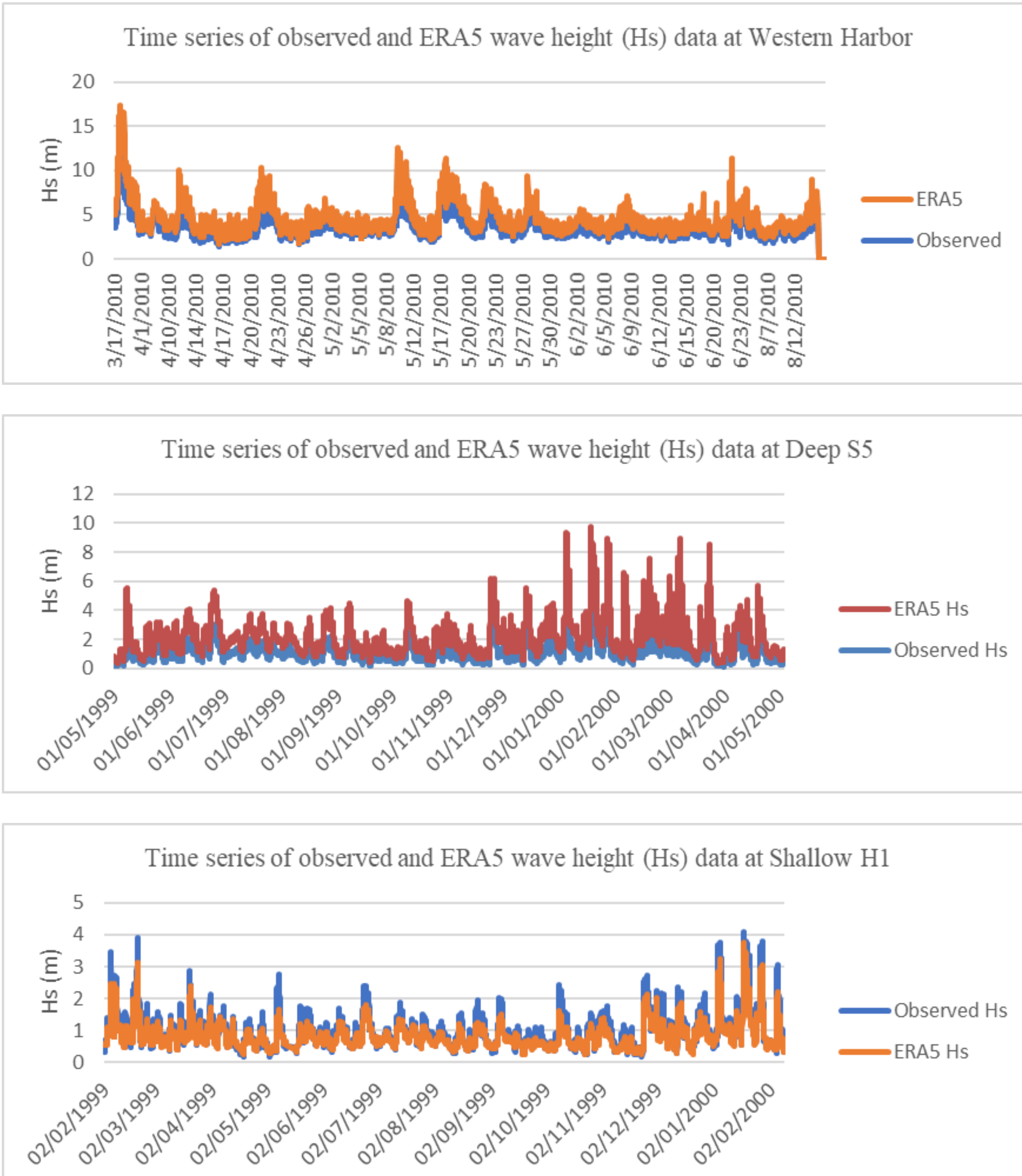


Figure 4: Time series of the SWH for ERA5 and the buoy at various positions.

Table 2. Mean, minimum, maximum, and standard deviation of the significant wave height (SWH) from the buoys and ERA5(the gray cells refer to the benthic sensor).

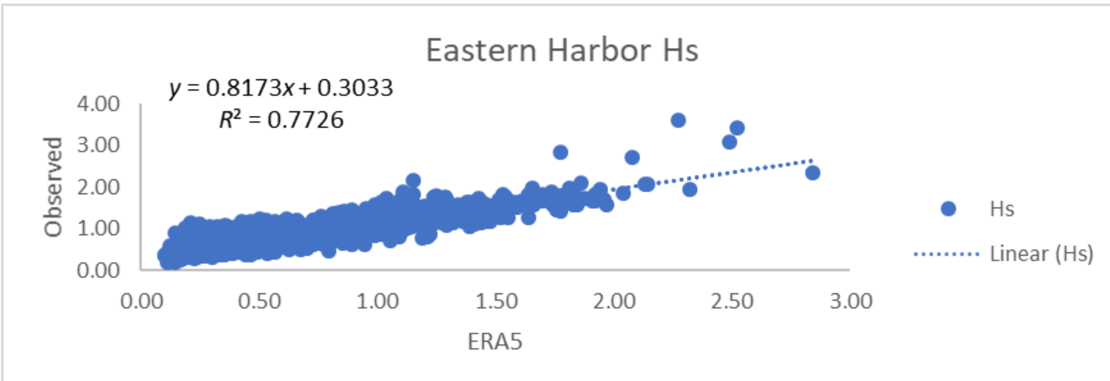
Station	Time		Observed data Hs				ERA5 data Hs			
	From	**To**	**mean**	**Min**	**Max**	**STD**	**mean**	**Min**	**Max**	**STD**
Alexandria Eastern Harbor	17-5-1996	7-1-1997	0.74	0.10	2.84	0.43	0.91	0.20	3.61	0.40
Alexandria Western Harbor	14-8-2008	7-10-2008	3.80	1.83	11.66	1.53	0.90	0.24	1.88	0.43
	17-3-2010	15-8-2010	3.78	1.40	14.46	1.43	0.82	0.16	2.99	0.47
Port Said Shallow H1	2-2-1999	2-9-2000	0.98	0.16	4.07	0.57	0.84	0.25	3.75	0.44
Rashid Deep S5	5-1-1999	5-3-2000	1.16	0.12	5.30	0.74	1.08	0.21	4.65	0.65

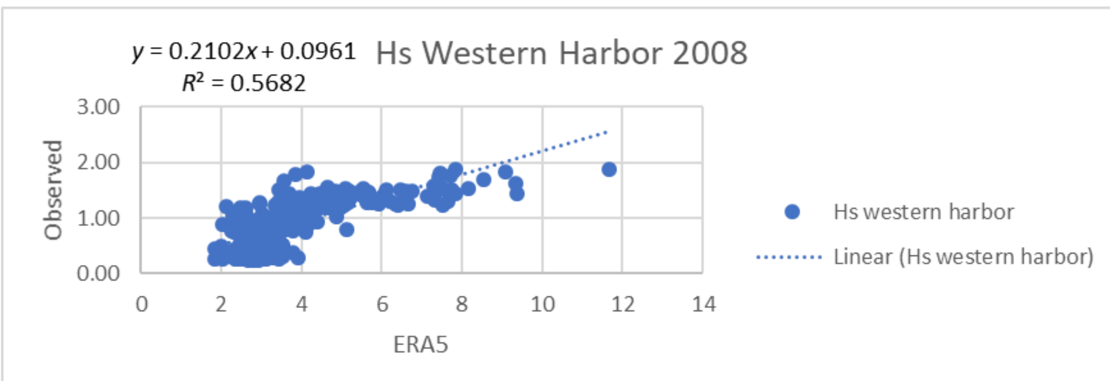
As is seen in (Table 2), the difference between the maximum and the minimum values for both data sets in each suit is equal (0.32 to 0.77) and (0.09 to 0.1) Except for Western Harbor 2008 and 2010 (9.78 to 11.47) and (1.24 to 1.59) respectively, while the difference in range between data values (0.08 to 0.17) also Western Harbor 2008 and 2010 (2.9 to 2.96).

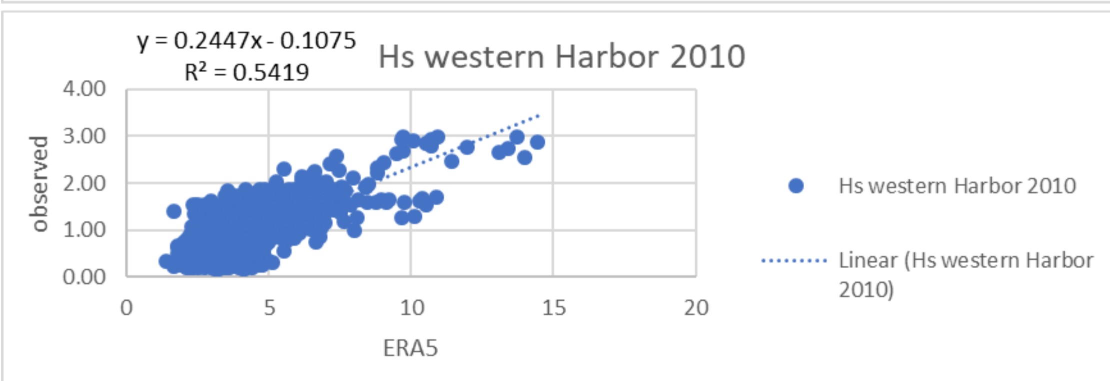
By comparing both results of the significant wave height in (Table 2), it was concluded that; differences in minimum and maximum values, together with in range Except for Western Harbor 2008 and 2010, don't make sense which may be the cause of the benthic sensor. Furthermore, the mean values of data sets didn't exceed 0.2, with a standard deviation (0.03 to 0.13), respectively, demonstrating equal quality and precision for data with the exclusion of Western Harbor 2008 and 2010 data, which reached 2.9, with a standard deviation of 1.

A scatter plot of the ERA5 SWH versus the buoy SWH and a least-squares linear fit to the datasets are presented in Figure 5. The latter demonstrates that the fit line's slopes are mostly near 1. The ERA5 SWH results are similarly compatible with buoy-measured SWH data in the Egyptian Mediterranean waters, as shown by comparison statistics (Table 3). The bias values are small (less than 0.01 m), respectively. All of the bias values are positive. Except for Western Harbor 2008 and 2010, this result implies that the measured SWH (observed) is greater than ERA5 data and may be caused by the buoy's sensor on benthic. As shown in Table 2, the maximum SWH in the two datasets is 11.66 and 14.46 compared to the ERA5 datasets, which are 1.88 and 2.99, making no sense.

The RMSE values are generally small (i.e., no more than 0.1m). SI reflects the dispersion between the measured and ERA5 datasets; the smaller the value, the better the correlation between them. The SI in the Western Harbor in 2008 and 2010 is the greatest, with the smallest correlation coefficient (0.754 and 0.736). The SI of the other locations is less than 0.2, and the correlation coefficient is0.88 in Eastern Harbor and reaches0.959 and 0.959 in shallow H1 and Deep5.







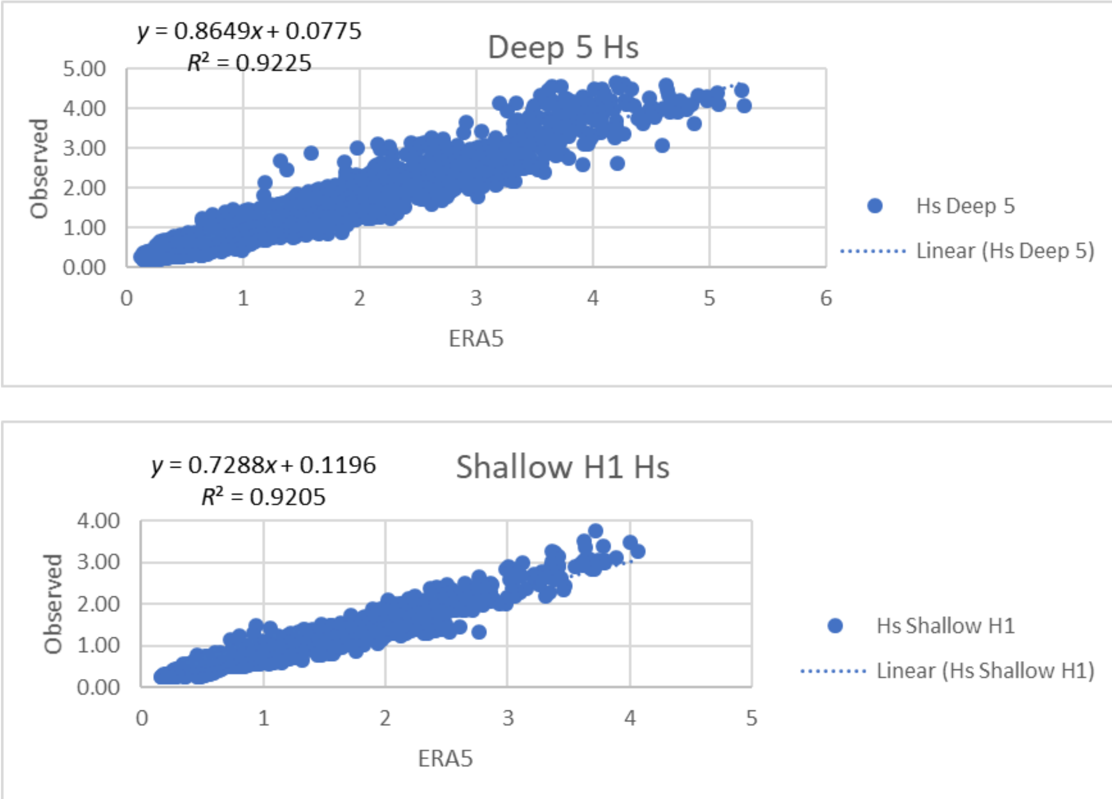


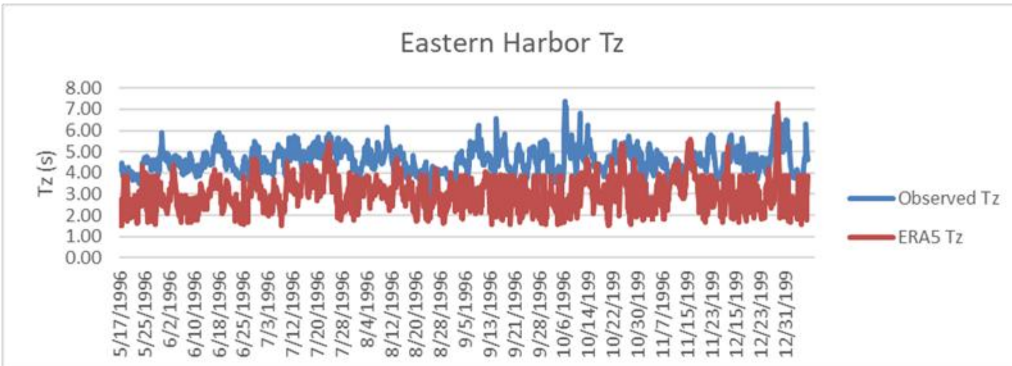
Figure 4: Scatter plot of ERA5 SWH with buoy SWH for different locations.

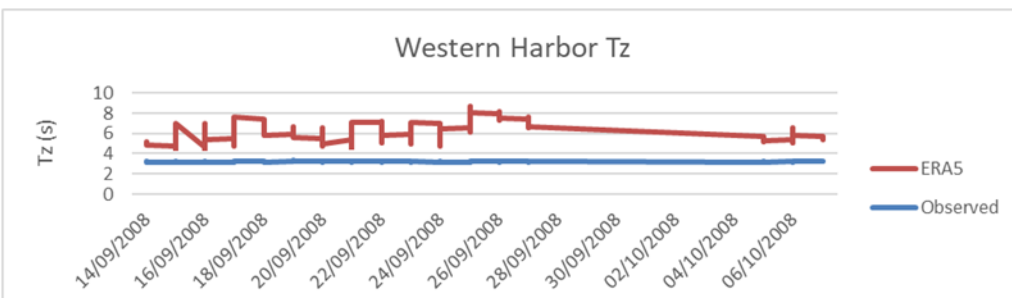
Table 3. Statistical results of SWH.

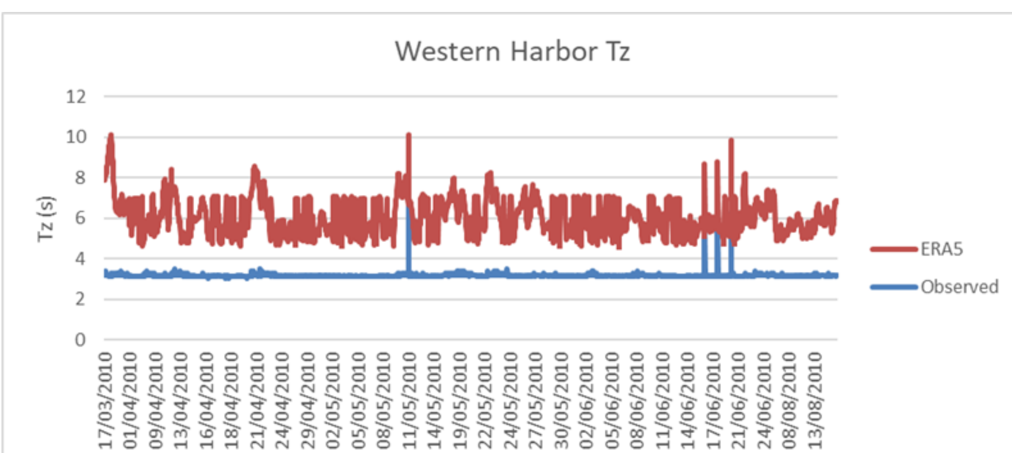
	Eastern Harbor	Western Harbor		Shallow H1	Deep S5
		2008	**2010**		
Count	1313	345	1967	4710	8252
Bias	0.000	−0.006	−0.003	0.000	0.000
RMSE	0.005	0.126	0.099	0.003	0.001
SI	0.007	0.033	0.026	0.003	0.001
Corr.	0.88	0.754	0.736	0.959	0.960

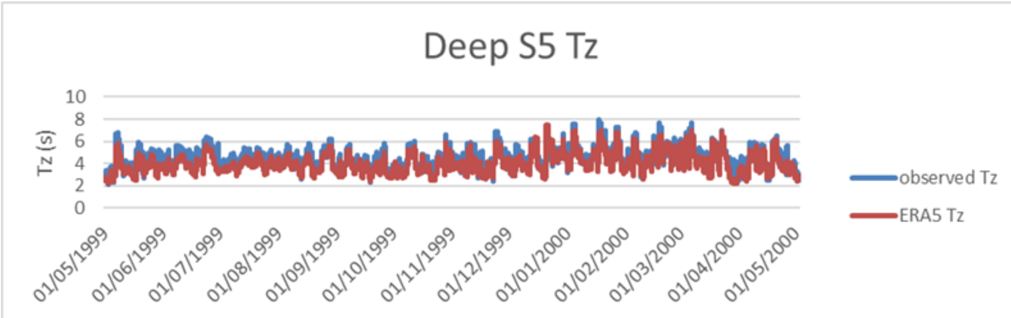
2.2 Mean Zero-Crossing Period

The zero-crossing period (Tz) is the inverse of the average number of times the ocean level moves up across the mean water level per second (Abdul Majeed *et al.*, 2010). The time series of Tm between ERA5 and the buoys at different locations are shown in Figure 6. For Western Harbor 2008 and 2010, the distribution of observation Tz is messy and thus considered invalid. Therefore, the data in Western Harbor in 2008 and 2010 were not used for evaluation. The statistical results of the mean, maximum of the Tz from the buoy, and ERA5 are shown in Table 4. Along Egypt Mediterranean, the measured buoy data show that the mean along the period for Tz in Eastern Harbor is 4.60s, in the Western harbor 2008 and 2010 is 3.17s, and in Deep S5 and Shallow H1 is1.16s and 4.23s, respectively. The maximum of the Tz in Eastern Harbor is 7.39s, in the Western Harbor 2008 and 2010 is 3.4s and 6.6, and in Deep S5 and Shallow H1 is5.3s and 7.97s.









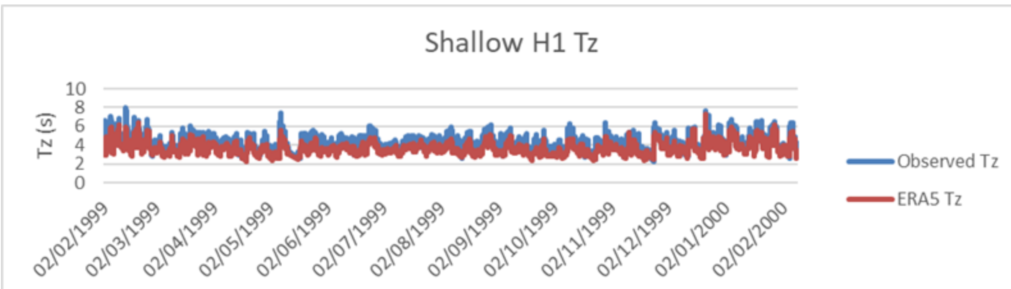
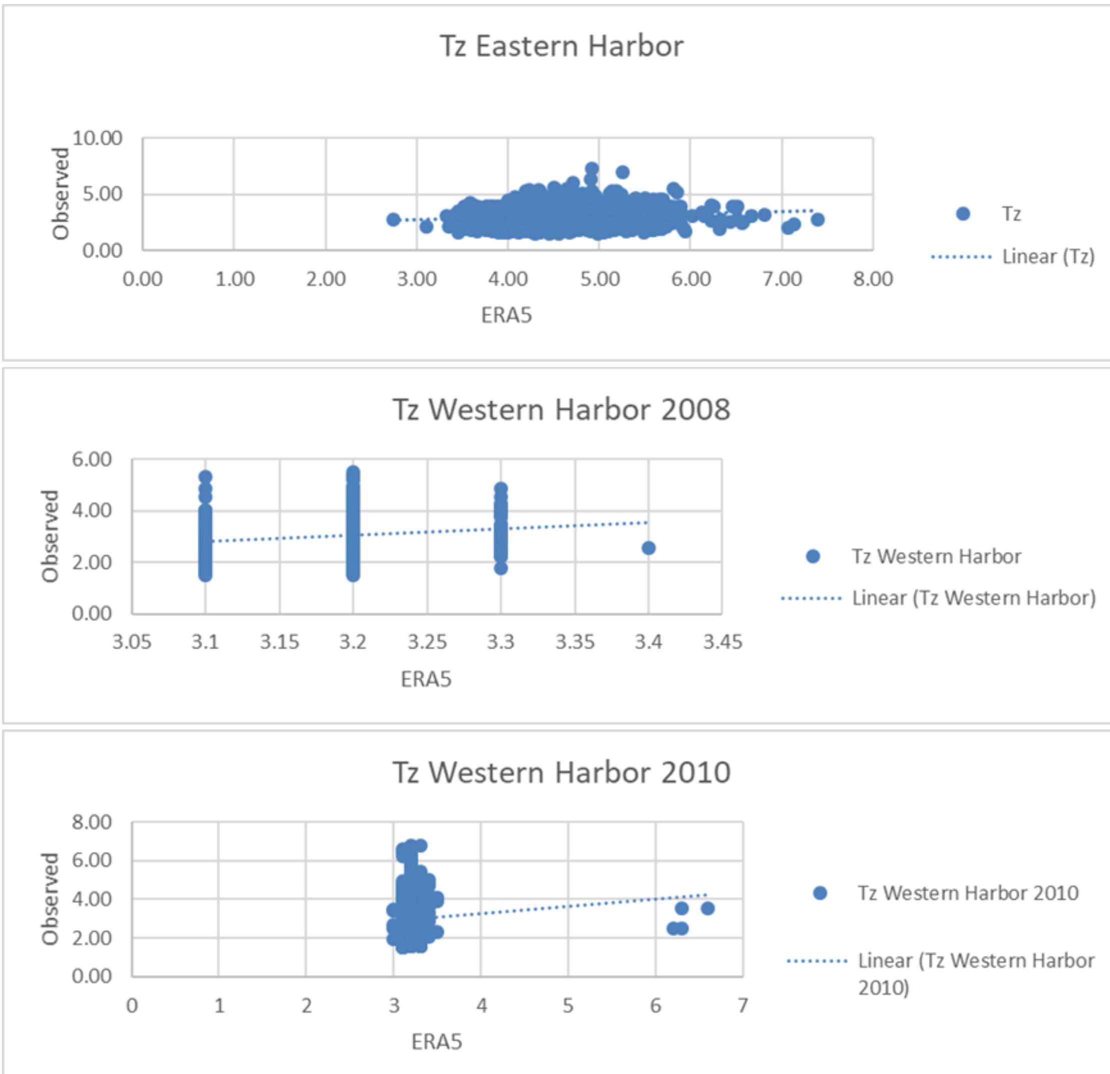


Figure 5: Time series of the Tz between ERA5 and the buoys at different locations.

Table 4. Mean, minimum, maximum, and standard deviation of the Tz from the buoy and **ERA5.**

Station	Time		Observed data Tz (s)				ERA5 data Tz (s)			
	From	To	Mean	Min	Max	STD	Mean	Min	Max	STD
Alexandria Eastern Harbor	17-5-1996	7-1-1997	4.60	2.74	7.39	0.59	3.00	1.52	7.27	0.80
Alexandria Western Harbor	14-8-2008	7-10-2008	3.17	3.10	3.40	0.07	2.99	1.52	5.52	0.89
	17-3-2010	15-8-2010	3.17	3.00	6.60	0.16	2.93	1.52	6.82	0.87
Port Said Shallow H1	2-2-1999	2-9-2000	4.23	2.28	7.97	0.87	3.67	2.29	7.27	0.69
Rashid Deep S5	5-1-1999	5-3-2000	1.16	0.12	5.30	0.74	1.08	0.21	4.65	0.65

A scatter plot of the ERA5 Tz versus the buoy Tz is shown in Figure 6, and a least-squares linear fit to the datasets. Tz's statistics results are presented in Table 5. The ERA5 Tz and the buoy Tz correlation coefficients show a misalignment for Eastern Harbor, Western Harbor 2008 and 2010 are 0.14, 0.184, and 0. 069. On the other hand, for Deep S5 and Shallow H1, the ERA5 Tz and the buoy Tz correlation coefficients are0.914 and 0.897.



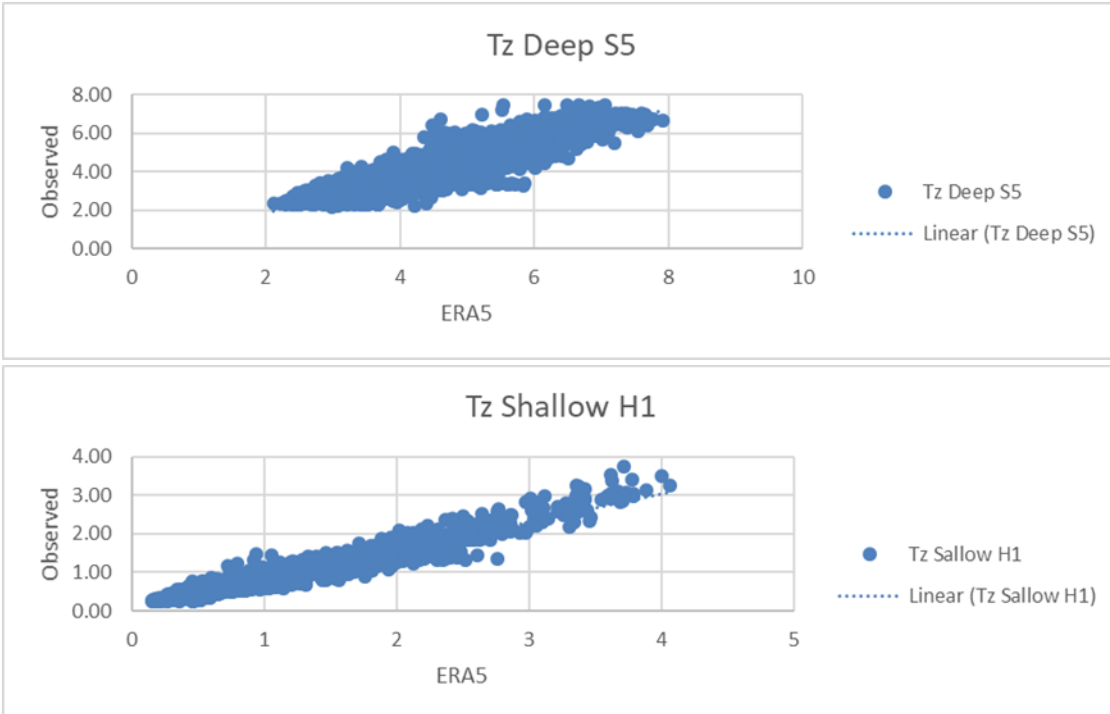


Figure 6: Scatter plot of ERA5 Tz with the buoy SWH for different locations.

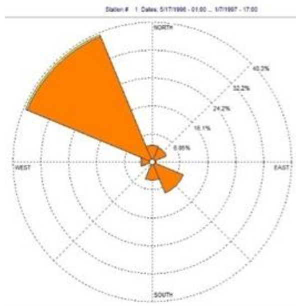
Table 5. Statistical results of Tz.

	Eastern Harbor	Western Harbor		Shallow H1	Deep S5
		2008	2010		
Count	1313	345	1967	4710	8252
Bias	−0.001	0.002	0.000	0.000	0.000
RMSE	0.025	0.074	0.007	0.010	0.004
SI	0.005	0.023	0.002	0.002	0.001
COR	0.14	0.184	0.069	0.897	0.914

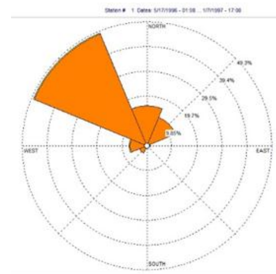
2.3 Wave Direction (WD)

The predominant wave direction at Alexandria Eastern Harbor was NW, according to observed and ERA5 data. Over Port Said and Rashid, observed and ERA5 data pointed to the same WD pattern with a prevailing NW wind direction. Only over the Alexandria Western Harbor2008 and 2010, the observed wave by the station (S4ADW) is not the same asERA5 data, which is predominant NW. Maybe, it is the case of affecting the depth of the station. In general, there was a good similarity between the performance of observed stations and ERA5 over the three stations. Moreover, the observed stations and ERA5 results of wave direction were closely related to the observations over

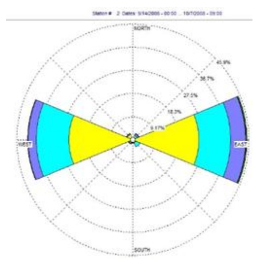
Alexandria Eastern Harbor, Port Said, and Rashid. Except for Alexandria Western Harbor, there is no common direction between observed station data and ERA5 data on the cause of the benthic sensor.



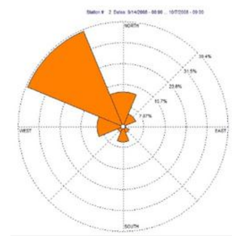
(a) Observed direction Eastern Harbor



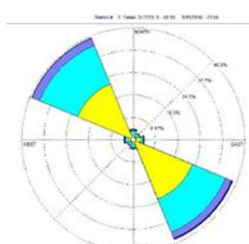
(b) ERA5 direction Eastern Harbor



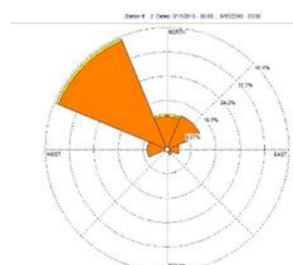
(a) Observed direction Western Harbor 2008



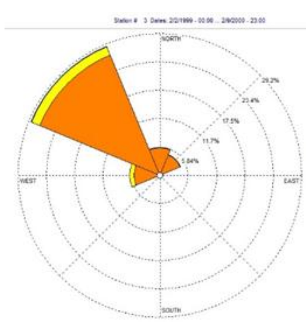
(b) ERA5 direction Western Harbor 2008

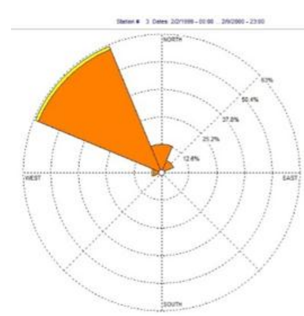


(a) Observed direction Western Harbor 2010

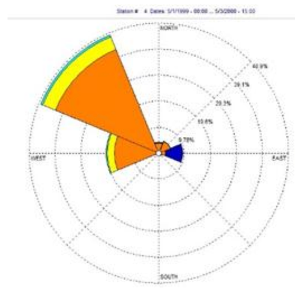


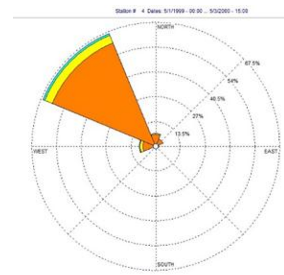
(b) ERA5 direction Western Harbor 2010





(a) Observed direction shallow H1 (b) ERA5 direction shallow H1





(a) Observed direction DEEP S5 (b) ERA5 direction DEEP S5

Figure 7: Wave rose for the observed ERA5 and observed stations result at the five different locations.

3 Summary and Conclusions

In this study, we evaluated the performance of ERA5 reanalysis SWH, Tz, and WD data at four locations over the southeastern Levantine Basin around Egypt's Mediterranean water by comparing the obtained data with in situ buoy measurements. Observations covering different seasons were used for the study.

Analysis showed that ERA5 overestimates the SWH along the southeastern Levantine Basin due to wind overestimation. The difference between the ERA5 SWH and the buoy SWH maximum, minimum, and mean reaches (9.78 to 11.47), (1.24 to 1.59) and (2.9 to 2.96), respectively, for Alexandria Western Harbor2008 and 2010, where a buoy (S4ADW) has a benthic sensor on it. The bias values are small (less than 0.01 m), respectively. All of the bias values are positive. Except for Western Harbor 2008 and 2010, this result implies that the measured SWH (observed) is greater than ERA5 data and may be caused by the buoy's sensor on benthic. As the latest generation of ECMWF's atmospheric reanalysis of the global climate, ERA5 is greatly improved. Like ERA-I, assessing the root causes of the biases and errors of ERA 5 remains difficult when a low-resolution global model is used in a somewhat complex basin with in situ observations in nearshore environments. Oceanographic, Orographic effects, and bathymetry may play an important role in this situation.

4 Recommendations for Future Research

a) It is necessary to calibrate and validate the data adequately when applying the global model and its reanalysis data to specific ocean areas.
b) Use long-term observed data and more buoys to evaluate the accuracy of ERA5 reanalysis data.

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