

Study of Sea Level Variation of Exclusive Economic Zone of Malaysia

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Since a decade, satellite altimetry has demonstrated its capability in measuring temporal change of the global mean sea level with a precision better than 1 mm/year. Here, sea level variation for four areas in Exclusive Economic Zone (EEZ) of Malaysia have been investigated using eleven years of Topex altimetry data. The recently updated environmental and geophysical corrections were applied in altimetry data processing. The analysis of Topex data presented is based on cycle by cycle averages using GOT00.2b and FES2002 ocean tide model. The time series of dynamic sea surface elevation clearly show El Niño effect on the end of 1997 and sea level rising in EEZ of Malaysia. Linear term of sea level variation for those areas are estimated at a rate between 2.5 – 8.8 mm/year. Comparison results between two ocean tide present that GOT00.2b better than FES2002 for shallow water such as Malacca Strait.

1. Introduction

Long-term sea level height variations are an important indicator of climate changes. Observations from satellite altimeters during the past three decades have provided dramatic descriptions of sea level variability but the spatial scales which could be reliably studied were limited by orbit uncertainty. Since last decades Topex-Poseidon was launched and the orbit determined from globally distributed network of laser and DORIS stations. Nowadays, Topex-Poseidon is used a reference for other satellite in multi satellites processing.

Although satellite altimetry records are still quite short compared to tide gauge data sets, this technique appears quite promising for the sea level change problem because it provides sea level measurement with large coverage. A precision better than 1mm/year of

measuring global sea level can be obtained using Topex-Poseidon. It is the one of remarkable results from satellite altimetry (Nerem et al.,1995).

Cecile et al. (2001) analyses the global mean sea level rise at rate 2.5mm/year. On time scales longer than 1 year, global mean sea level change results from two main causes: (i) volume change due to seawater density change in response to temperature and salinity variations (the two parameters having opposite effects on sea level) and (ii) mass change due to exchange of water with atmosphere and continents, including glaciers and ice sheets, through precipitation, evaporation, river runoff, and ice melting.

2. Topex Data Processing

The Topex-Poseidon satellite, carrying two altimeters, Topex and Poseidon, was launched in August 1992 to study the large scale ocean circulation and its temporal variations (Fu et al., 1994). The satellite has been placed on a 66° inclined orbit at 1336km altitude. The orbital repeatability (or orbital cycle, i.e., time interval for the satellite ground tracks to exactly superimpose) is 9.916 days. This corresponds to an inter-track spacing of 350 km at the equator. Altimeter range measurements are provided at 1- second interval, i.e., about 6 km along. In this study, only Topex data only are being considered.

Table 1: Geophysical corrections applied to Topex data

Corrections	Model
Orbit	JGM-3
Inverse Barometer	1013.3 mbar
Dry Tropo & IB	ECMWF
Wet Tropo	ECMWF
Ionospheric	Smooth Dual-Freq.
Earth Tide	Applied
Ocean Tide	GOT00.2b/FES2002
Loading Tide	GOT00.2b/FES2002
Geoid/MSS	CLS01 MSS
Pole tide	Applied
Sea State Bias	BM3/BM4

Topex data covering the time span of about 11.5 years (from January 1993 through May 2004, cycles 11-429) are used in this study. Data retrieval and analyses were carried out using Radar Altimeter Database System (RADS). Table 1 summarizes the various corrections applied to the Topex altimeter range measurements. The corrections include the ionospheric delay, dry and wet tropospheric corrections, solid Earth and ocean tides, ocean tide loading, pole tide, electromagnetic bias (EMB) and inverse barometer (IB) correction.

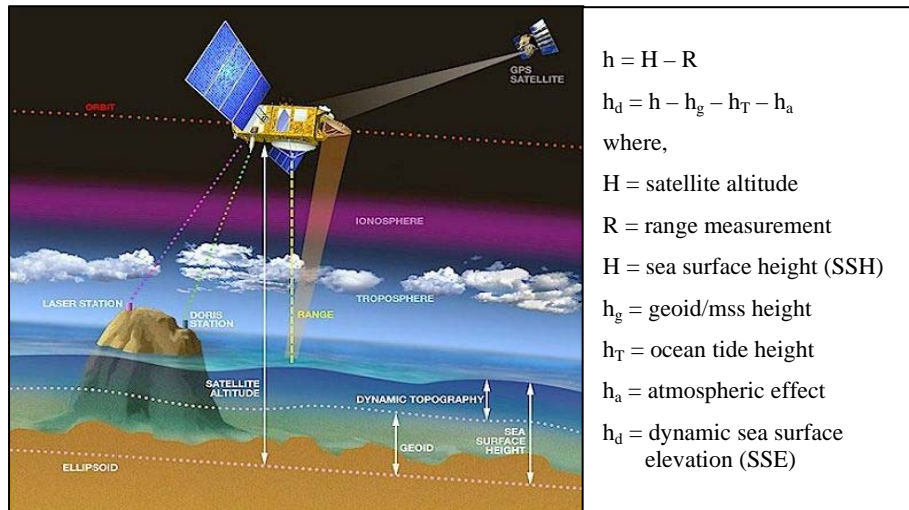


Figure 1: Principle of satellite altimetry

The Topex orbits are based on the JGM-3 geopotential model (Tapley et al., 1996). Instantaneous sea surface heights (SSH) above the ellipsoid used as reference for the satellite altitude are generated along the satellite tracks from the difference between the radial component of the orbit and the corrected altimeter range measurement. Since we are interested in the time-variable component of SSH, e.g., the sea surface height above the geoid or mean sea surface (MSS), the static part, i.e., the height of the geoid above the reference ellipsoid has been removed from SSH data at each latitude-longitude location. For this purpose, the mean sea surface CLS01 is being used as reference surface.

For the purpose of mapping the geographical distribution of the sea level variations over the 11.5 years, the IB correction to individual SSH measurements is applied while the global mean pressure is fixed at 1013mb. The later correction is an instantaneous static local response of the sea level to atmospheric pressure variations, the total pressure at the ocean bottom is assumed to be constant. The standard sea level correction is expressed through the relationship: $-0.9948 (P - P_{ref})$ (cm) where p is the instantaneous local surface pressure (in rob) and P_{ref} a reference pressure. P_{ref} is assumed constant (value of 1013.3 mb is used), Minster et al. (1995). In the following, the instantaneous sea surface heights is referenced to the CLS01 mean sea surface after removal of atmospheric effect and ocean tide. This is called sea surface elevation (SSE).

Four study areas within Malaysian EEZ were selected as shown in Figure 2; South China Sea, Sulu Sea, Malacca Strait and Celebes Sea. Global Ocean Tide (GOT00.2b) and Finite Element Solution (FES2002) tide models were used in the data reduction. The mean sea level time series was derived by averaging the altimeter data for every orbital cycle i.e. 10 days.



● Tide Gauge Station

Figure 2: Study areas

3. The Malaysian EEZ Mea sea level Variation: Some Initial Results

For both South China Sea and Malacca Strait, the mean Sea Level rise is clearly seen from altimeter data. The short term periodic circulation of mean sea level is being revealed at open South China Sea using both tide models. On the other side, the tide models do not seem to fit very well for the shallow Malacca Street where the short term ocean circulation seems to be rather noisy. This is due to the fact that Malacca Strait is narrow and shallow water area. The GOT00.2b tide model appears to fit slightly better than FES2002 for this area.

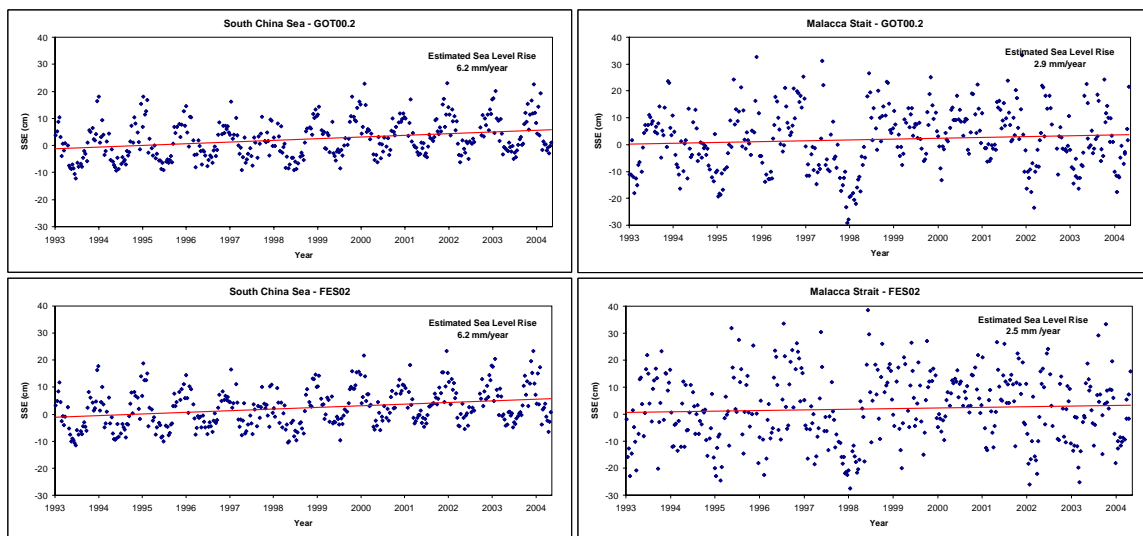


Figure 3: Time series of South China Sea (left) and Malacca Strait (right) using GOT00.2b (top) and FES2002 (bottom)

Figure 3 summarizes results of Mean Sea Level variation computations for the Malacca Strait and South China Sea. Using the straight line fitting, the sea level rise for South China Sea and Malacca Strait are estimated at 6.2mm/year and 2.5-2.9mm/year respectively.

Mean Sea Level variations for Sulu Sea and Celebes Sea are shown in Figure 4. Both areas have shown similar pattern of sea level variations, and both tide models seem to fit well to these areas. The rate of mean sea level rise are estimated at 6.9-7.0mm/year and 8.1-8.8mm/year respectively. The effect of EL-Nino on sea level is clearly seen where the sea level begins to fall in 1997 and back to the normal in the middle of 1998. Figure 5 shows the 2nd and 5th order polynomial fitting for the areas to model the long term variations. The two neighboring seas seem to have interesting common pattern of sea level fall in 2000.

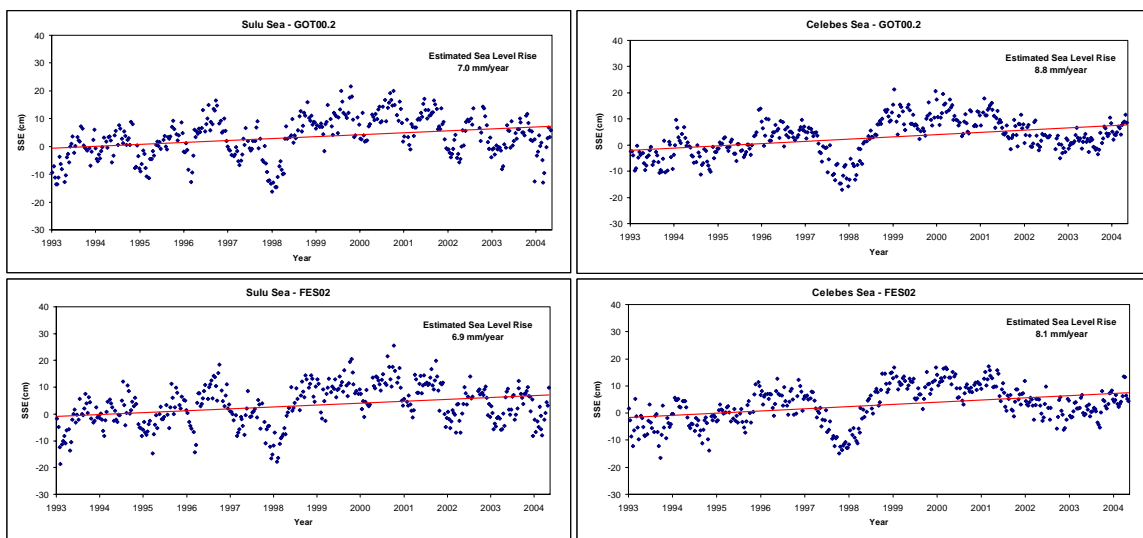


Figure 4: Time series of Sulu Sea (left) and Celebes Sea (right) using GOT00.2b (top) and FES2002 (bottom)

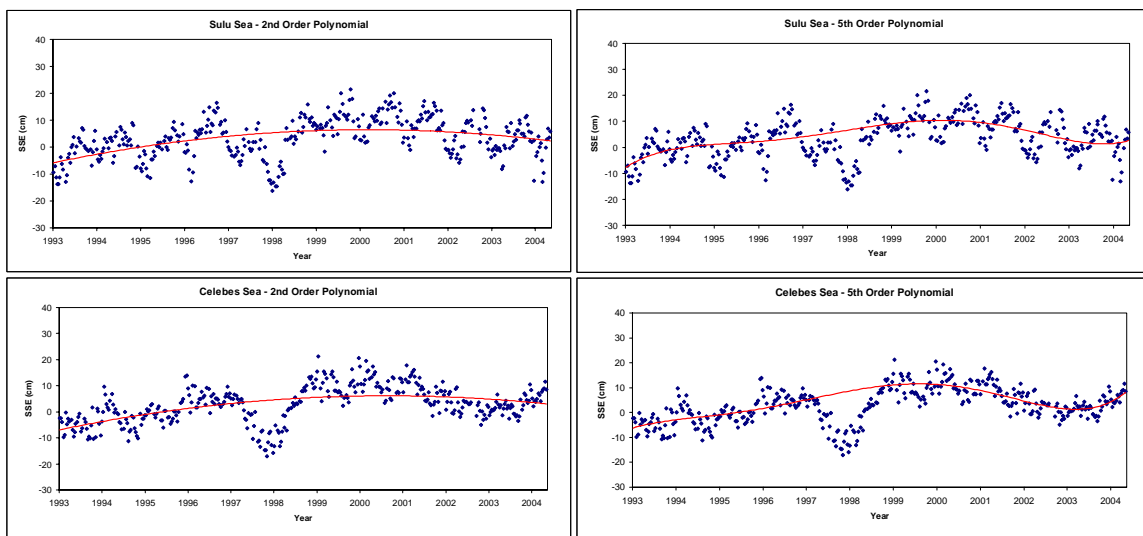


Figure 5: The long term Mean Sea Level Variation for Sulu and Celebes Sea

4. Comparison with Local MSL Data

A network of 21 continuously operating tide gauge stations have been established since 1984 along the coastal areas of Malaysia. The main objective of the establishment of the network is to enable a continuous time series of sea level heights be obtained for the purpose of establishing a vertical datum for the nation. The available tidal records are shown in Table 2 and their MSL values is given in Figure 6.

Table 2: Computed yearly height of mean sea level (in metres)

Year	Tide Gauge Station								
	WEST COAST					EAST COAST			
	Lumut	Port Kelang	Tanj. Keling	Kukup	Johor Bahru	Tanj. Sedili	Tanj. Gelang	Cendering	Geting
1984	–	3.678	–	–	2.852	–	–	–	–
1985	2.206	3.651	2.868	–	2.828	–	–	2.187	–
1986	2.163	3.609	2.838	3.987	2.832	–	–	2.183	–
1987	2.145	3.579	2.810	3.962	2.820	2.373	2.767	2.175	2.252
1988	2.216	3.654	2.872	4.015	2.856	2.406	2.805	2.213	2.305
1989	2.201	3.635	2.855	4.009	2.860	2.405	2.796	2.209	2.294
1990	2.170	3.611	2.833	3.983	2.823	2.419	2.776	2.182	2.267
1991	2.158	3.583	2.802	3.994	2.834	2.393	2.786	2.196	2.290
1992	2.186	3.615	2.850	3.996	2.831	2.385	2.775	2.175	2.253
1993	2.184	3.625	2.847	3.983	2.833	2.384	2.776	2.187	2.297
1994	2.140	3.578	2.809	3.956	2.847	2.388	2.773	2.183	2.286
1995	2.218	3.657	2.871	4.021	2.877	2.407	2.813	2.222	2.309
1996	2.223	3.669	2.870	4.018	2.854	2.421	2.802	2.194	2.323
1997	2.122	3.540	2.763	3.931	2.824	2.381	2.782	2.188	2.298
1998	2.206	3.654	2.864	4.006	2.849	2.404	2.803	2.207	2.284
1999	2.245	3.694	2.898	4.048	2.888	2.440	2.840	2.243	2.327
2000	2.249	3.711	2.899	4.050	2.884	2.436	2.833	2.240	2.271
Mean	2.189	3.632	2.847	3.997	2.847	2.403	2.795	2.199	2.290

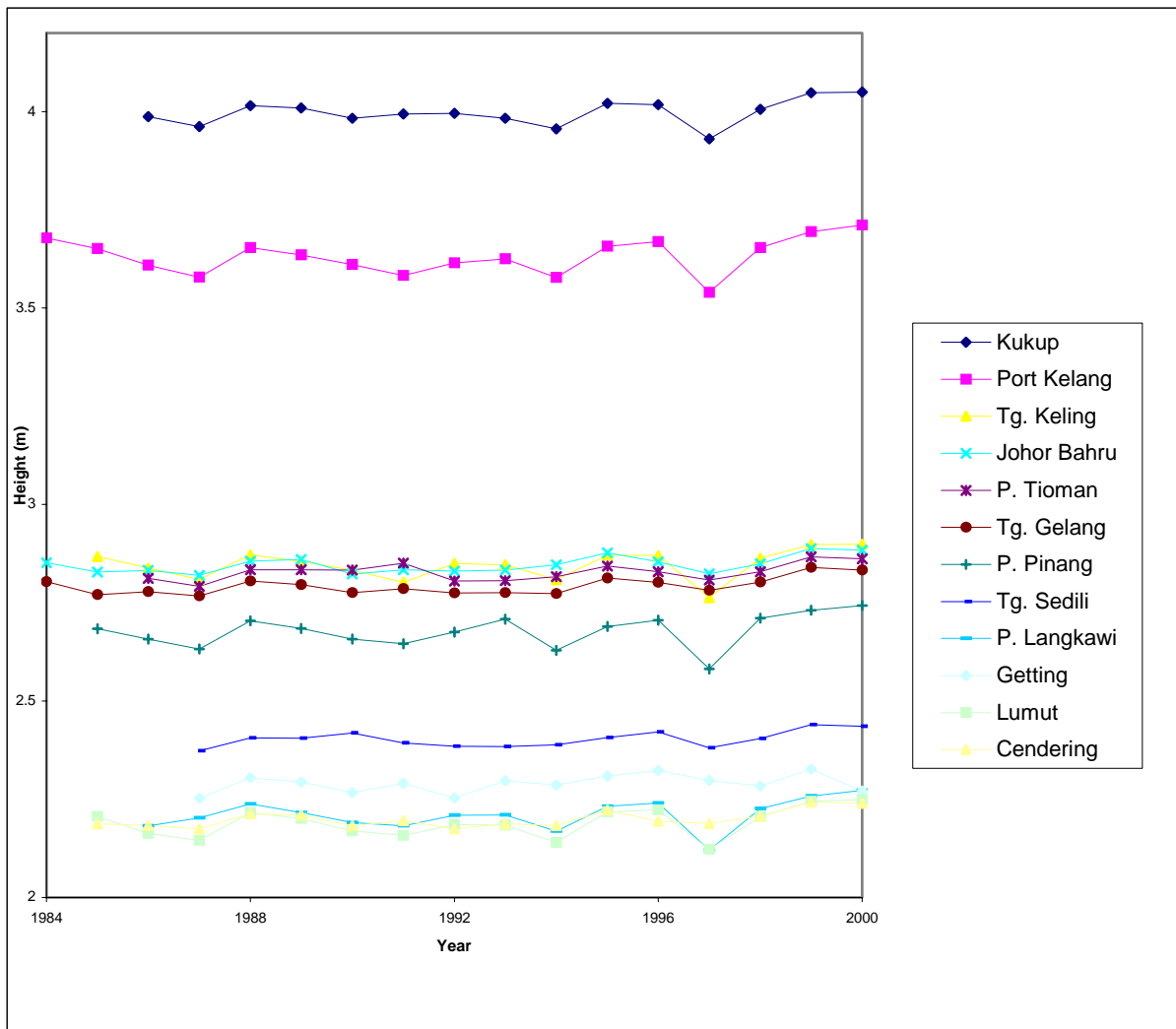


Figure 6: Yearly mean sea levels for all tide gauge stations in Peninsular Malaysia

The trend rates are given in Table 3 and represented graphically in Figure 7. It shows that a trend in sea level around Peninsular Malaysia exists and varies quite significantly from one location to another. It can also be seen that the linear trends of the MSL variations are positive, indicating an overall rise in the sea level around the coast of Peninsular Malaysia. The rising trend ranges from 1.7 ± 6.0 mm/year at Tanjung Keling on the west coast to 3.4 ± 0.2 mm/year at Tanjung Gelang on the east coast. Taking the average of the group, the indication is that relative sea level trends in Peninsular Malaysia show 2.4 ± 0.5 mm/year.

Table 3: Sea Level Rise for Peninsular Malaysia From Tide Gauges

	Tide Gauge Station								
	West Coast					East Coast			
	Lumut	Port Kelang	Tanj. Keling	Kukup	Johor Bahru	Tanj. Sedili	Tanj. Gelang	Cendering	Geting
	Data Used	1985 to 2000	1984 to 2000	1985 to 2000	1986 to 2000	1985 to 2000	1987 to 2000	1987 to 2000	1985 to 2000
Mean	2.189	3.632	2.847	3.997	2.847	2.403	2.795	2.199	2.290
Linear Trend (cm/yr)	0.28	0.18	0.17	0.26	0.22	0.25	0.34	0.26	0.21
Std. Error (cm/yr)	± 0.04	± 0.05	± 0.60	± 0.03	± 0.02	± 0.02	± 0.02	± 0.62	± 0.02

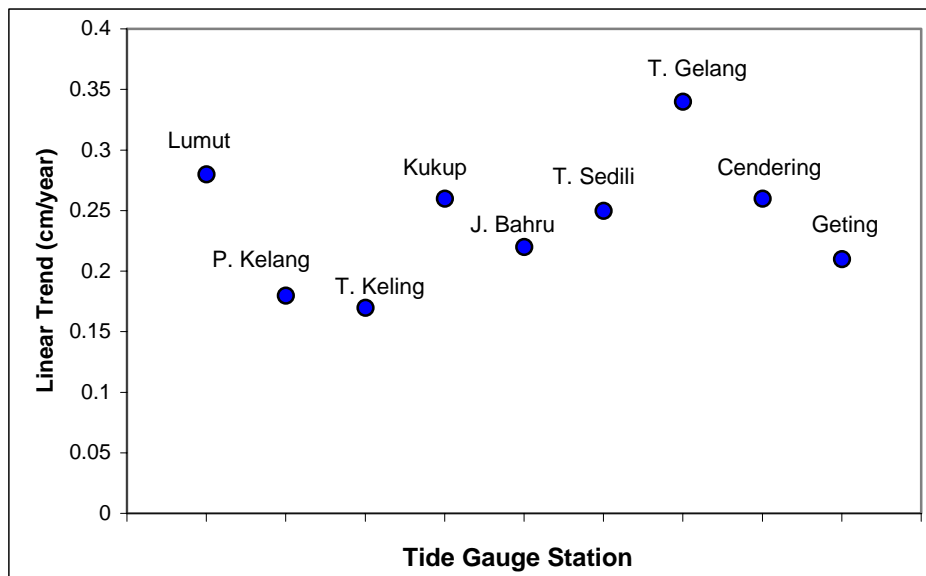


Figure 7: Ordered plot of linear trend estimate of mean sea level

The rising trend of observed MSL on the west coast ranges from 1.7mm/year (Tanjung Keling) to 2.8mm/year (Lumut). This shows some agreement with the satellite altimetric derived sea level rise of 2.5 to 2.9mm/year in the Malacca Straits. Higher rising trend of MSL from tidal measurement is observed on the east coast ranges from 2.1mm/year

(Getting) to 3.4mm/year (Tg. Gelang). However, satellite altimetric derived sea level rise of 6.2mm/year is being observed in the South China Sea. On the east coast, the yearly rate of sea level rise derived from satellite altimetric measurement is found to be twice as much of their corresponding value deduced from the tidal records. Since most of the tide gauges are located along the coastline of the Peninsular, direct comparison with altimetry data will obviously introduce some discrepancies particularly due to the lack of altimeter tracks close to the shore.

5. Conclusion

Satellite altimetry records may still be too short to detect any long term sea level rise possibly associated with global warming and the results discussed above may hardly be comparable to those based on multi-decadal tide gauge records. However, the Topex sea level time series reveal that since 1993, the mean sea level in EEZ of Malaysia has been rising at a rate of between 2.2-8.8 mm/year. The sea level change increasing from Malacca Strait to Celebes Sea. Mean sea level using GOT00.2b shows the better results for shallow water. As longer time series become available, confidence on the results will increase. Satellite altimetry will then provide important constraints on climate models through the determination of absolute sea level changes, hence allowing an estimate of the 'true' volume and mass change of the oceans at interannual time scales.

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