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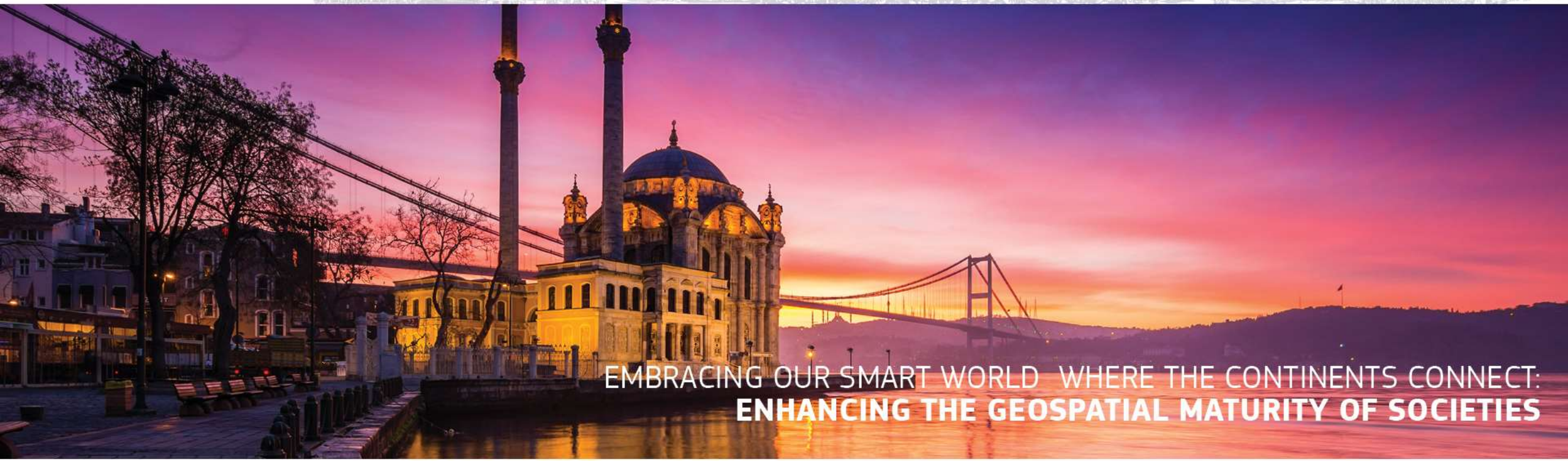

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EMBRACING OUR SMART WORLD WHERE THE CONTINENTS CONNECT:
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Paper ID: 9253 *(Peer Review)*

Interpreting the Sea Level Variability over Malaysian Seas using Multi-mission Satellite Altimeter

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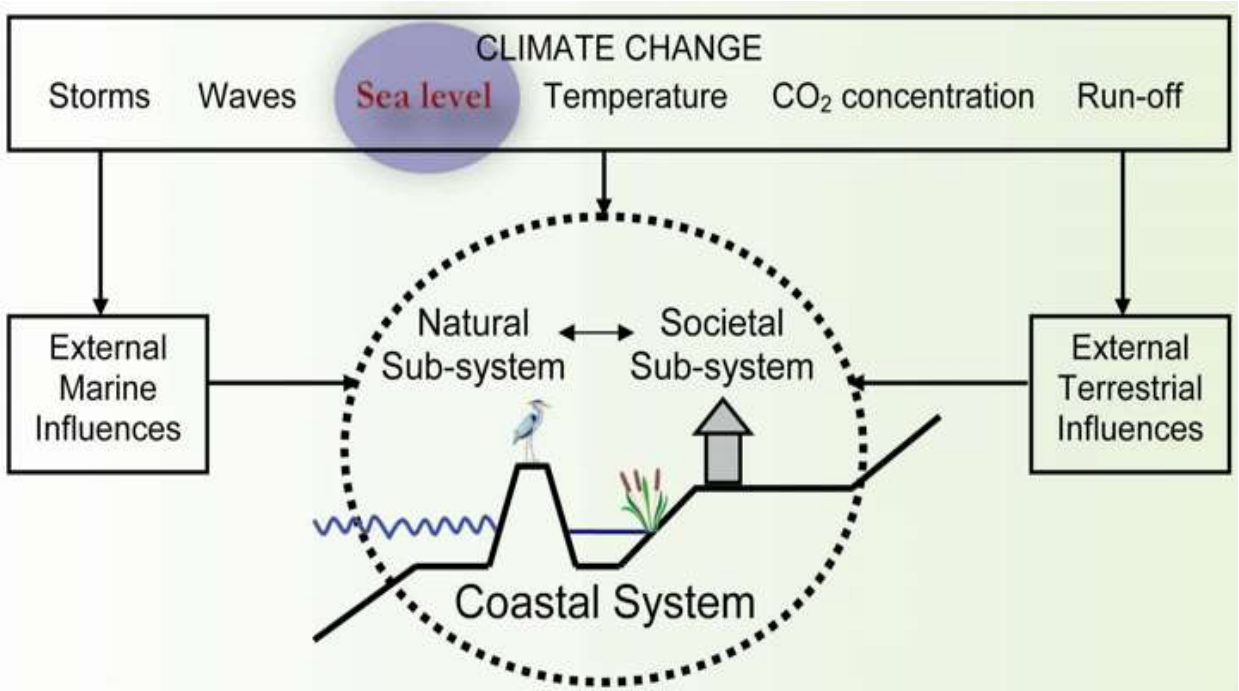
CONTENT

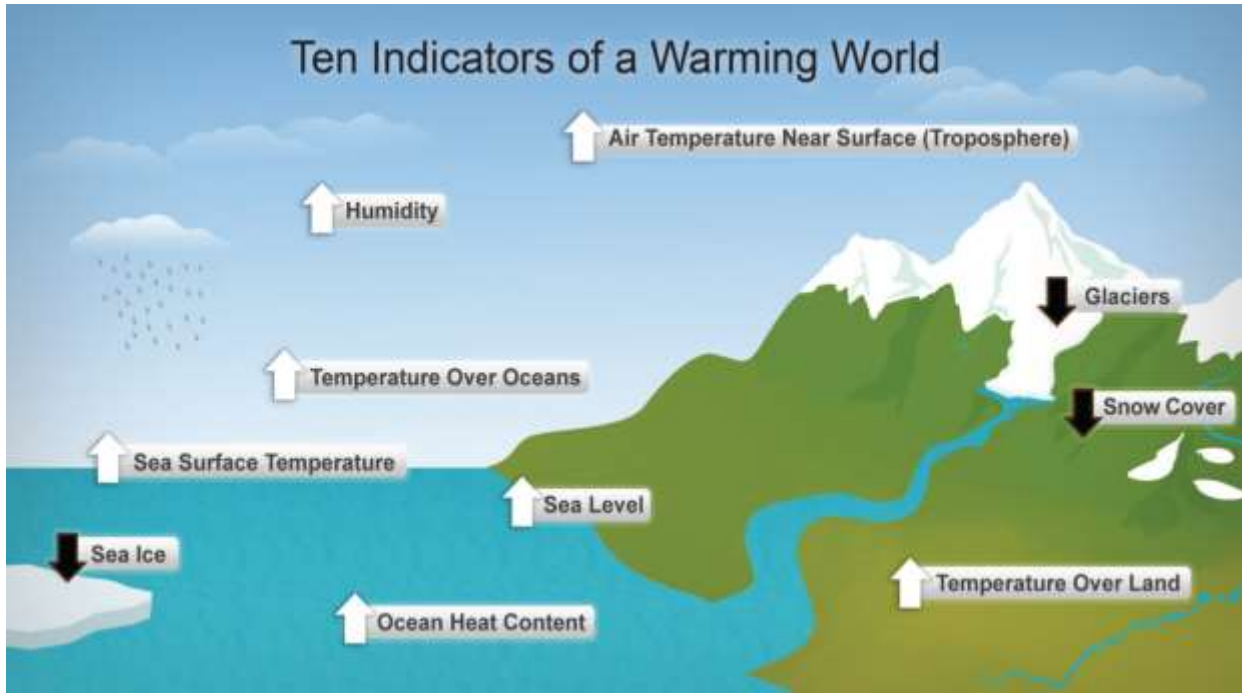
INTRODUCTION

Sea level rise scenarios within the context of climate risk assessment in the coastal zone



(Know Climate Change, 2017)

Impacts of Climate Change



(Source : Effects of Global Warming, US National Oceanic and Atmospheric Administration: National Climatic Data Center, 2010)

Geographical Location

Motivation of this study:

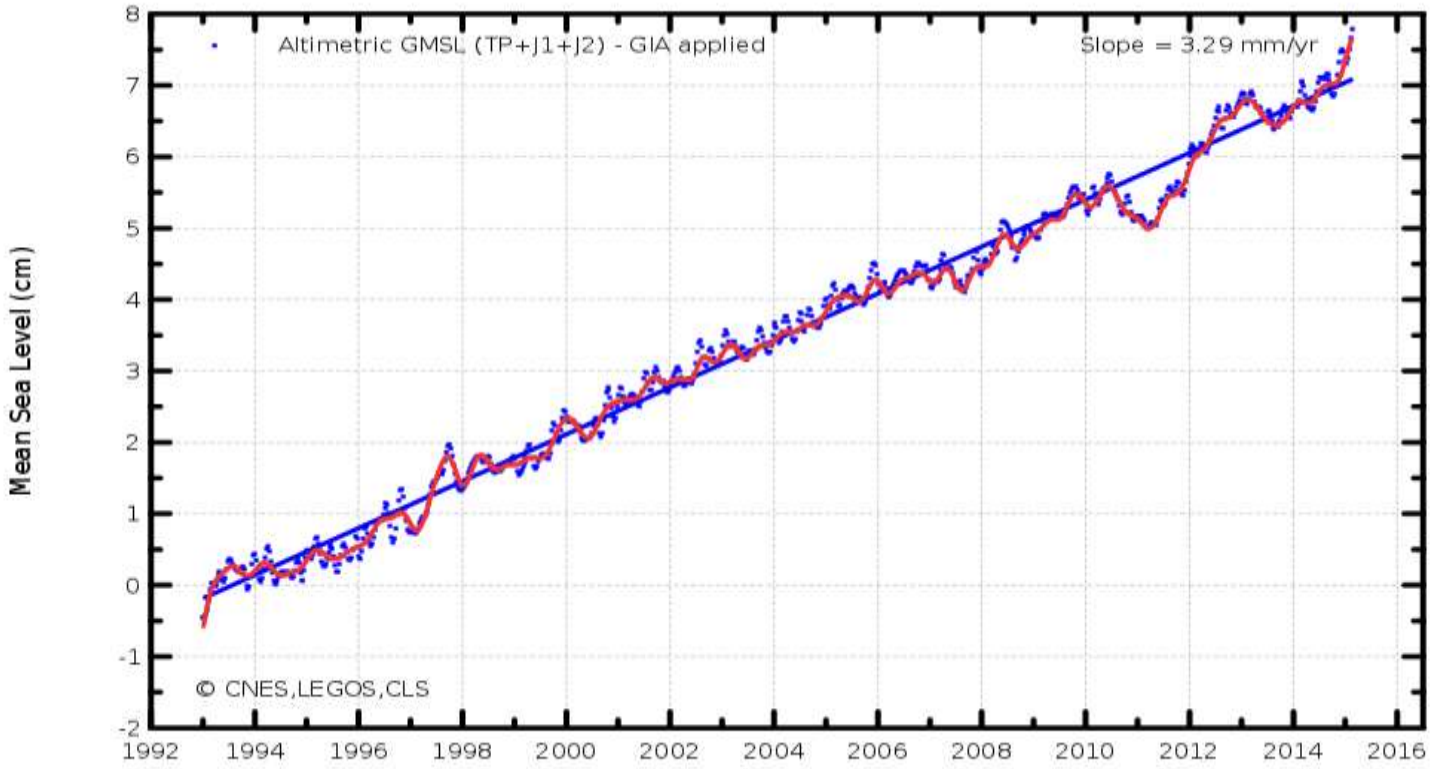
- Surrounded by marine areas
- Low-lying coastal areas
- Flash flood due high tide
- Tide Gauge: data-sparse and no long term record from deep-ocean

Flash flood – George Town, Penang

Flash flood due to high tide

INTRODUCTION

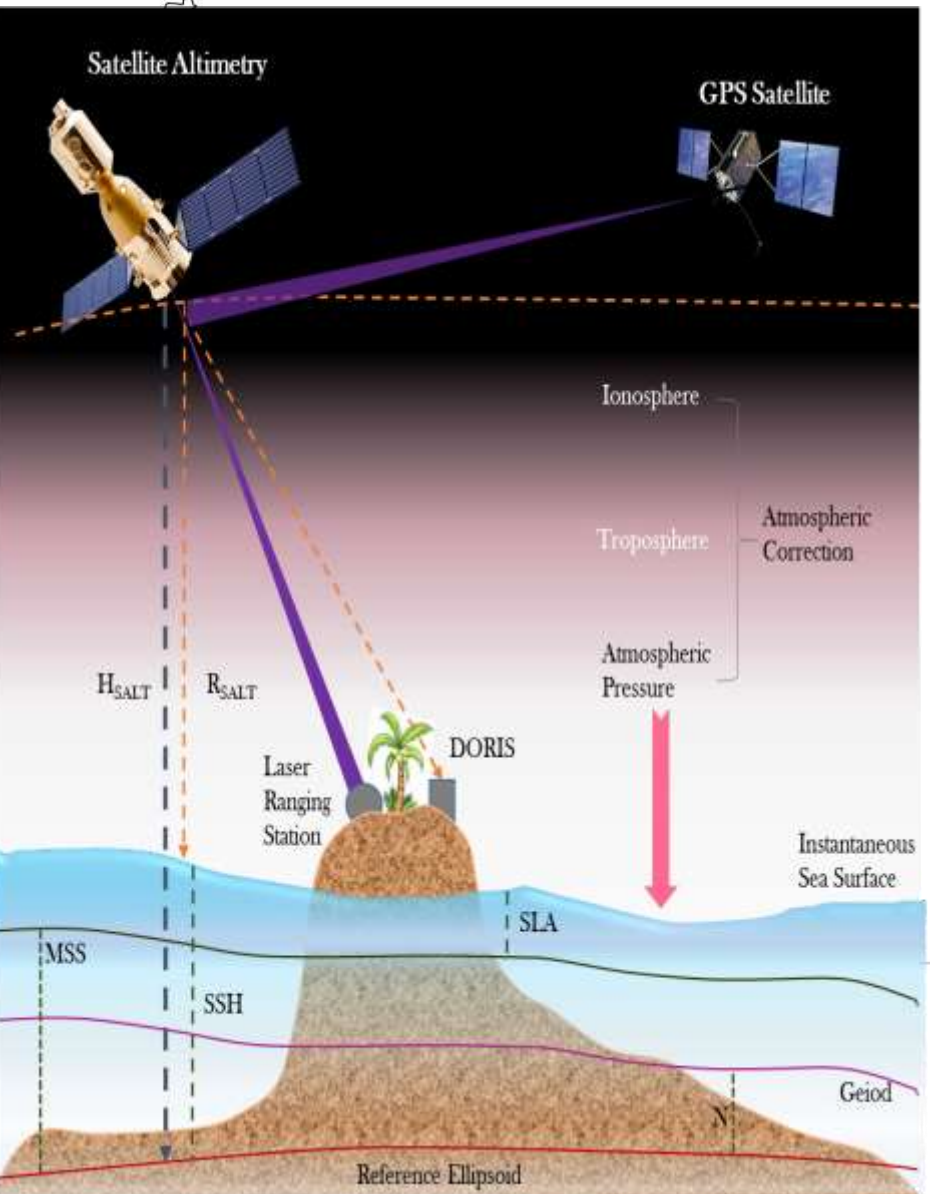
Global Sea level Rise: Topex, Jason-1 & Jason-2



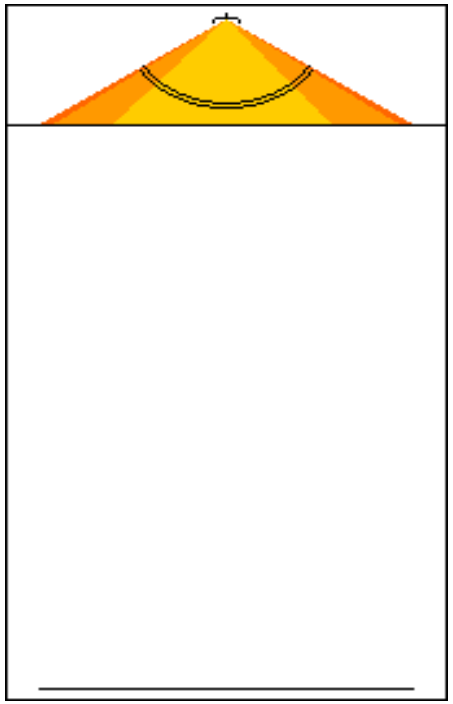
How fast the rate of SLR in the Malaysian seas?

IPCC-A rise of just 20 centimetres, could result in the displacement of more than 300 million people (*Parry et al., 2007*)

Altimeter Principle



Radar pulse reflecting at the sea surface



H_{SALT} = Satellite Orbit Height
R_{SALT} = Altimeter Range
SSH = Sea Surface Height
MSS = Mean Sea Surface
SLA = Sea Level Anomaly
N= Geoid Height

$$SSH = H_{SALT} - R_{SALT}$$

$$SLA = SSH - MSS$$

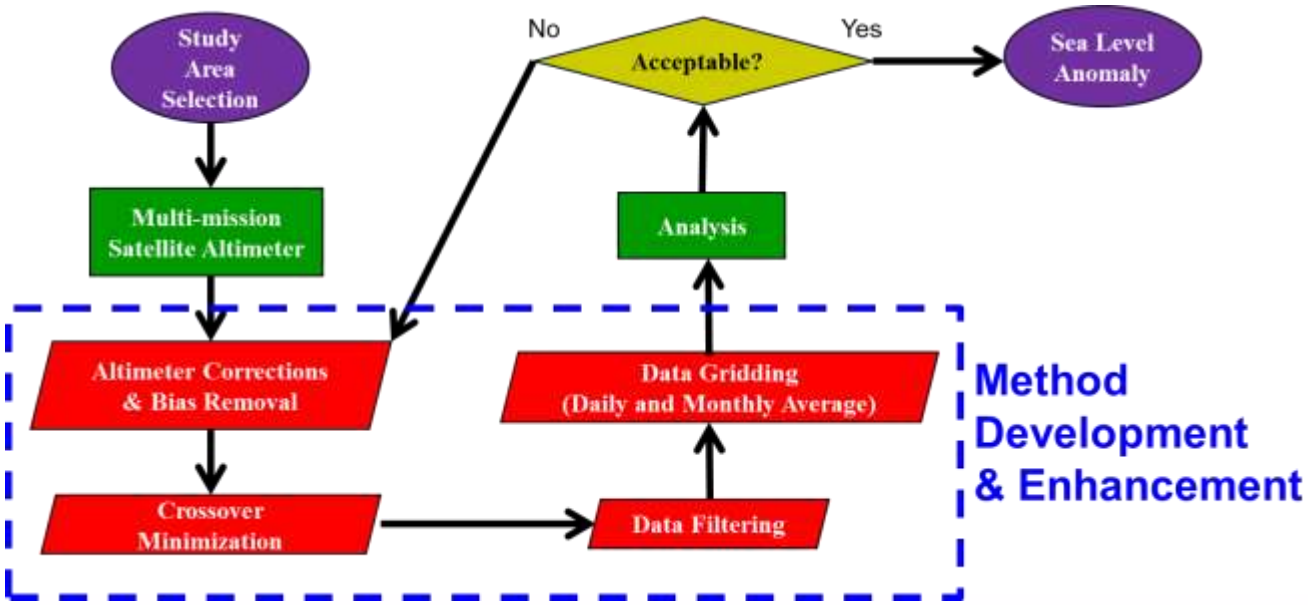
SLA: *The diff. between the time-independent sea surface height (SSH) and the mean sea surface (MSS)*

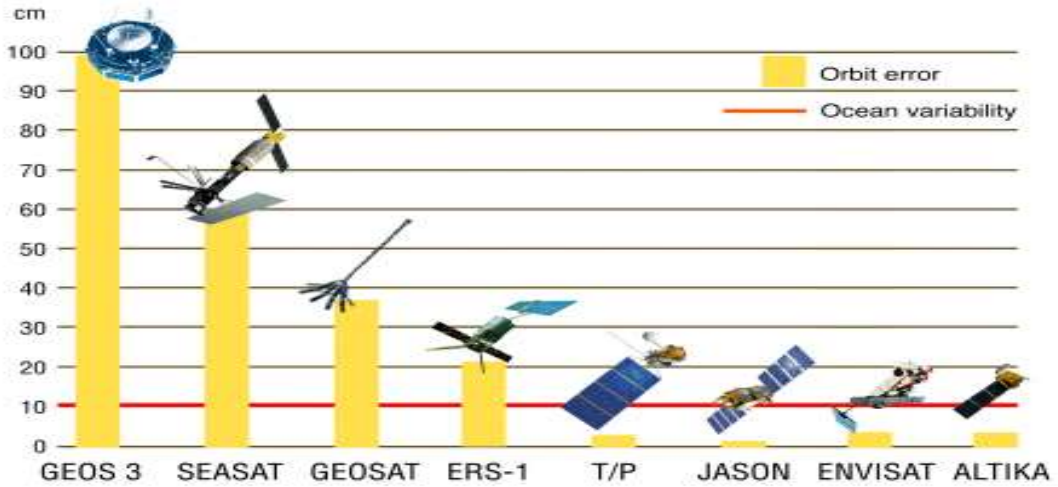
DATA & METHODS

Multi-mission Altimetry Data in RADS:

- Topex, Jason-1/2, ERS-1/2, ENVISAT, Cryosat, Saral/ Altika
- January 1993 – December 2015 (~ 23 years)

DATA PROCESSING IN RADS





Satellite	Sponsor	Repeat Period	Track Spacing	Inclination	Perigee	
TOPEX	NASA & CNES	9.9156 days	315 km	66°	1340 km	TOPEX Class
Jason-1	NASA & CNES	9.9156 days	315 km	66°	1336 km	
Jason-2	NASA & CNES	9.9156 days	315 km	66°	1325 km	
ERS-1	ESA	35 days	80 km	98.5°	780 km	ERS Class
ERS-2	ESA	35 days	80 km	98.5°	785 km	
EnviSat	ESA	35 days	80 km	98.5°	796 km	
Cryosat	ESA	30 days	250 km	92 °	717 km	
Saral	ISRO/ CNES	35 days	75 km	98.5°	800 km	

(AVISO, 2017)

DATA & METHODS

Correction/Model	Editing (m)		Description
	Min	Max	
Orbit/ Gravity field			All satellites: EIGEN GL04C ERS: DGM-E04/D-PAF
Dry troposphere	-2.4	-2.1	All satellites: Atmospheric pressure grids (ECMWF)
Wet troposphere	-0.6	0.0	All satellites: Radiometer measurement
Ionosphere	-0.4	0.04	All satellites: Smoothed dual-frequency, ERS: NIC09
Dynamic atmosphere	-1.0	1.0	All satellites: MOG2D
Ocean tide	-5.0	5.0	All satellites: GOT4.8
Load tide	-0.5	0.5	All satellites: GOT4.8
Solid earth tide	-1.0	1.0	Applied (Elastic response to tidal potential)
Pole tide	-0.1	0.1	Applied (Tide produced by Polar Wobble)
Sea state bias	-1.0	1.0	All satellites: CLS non-parametric ERS: BM3/BM4 parametric
Reference	-1.0	1.0	DTU13 mean sea surface
Engineering flag			Applied
Applied reference frame biases*			TOPEX Jason-1 Jason-2

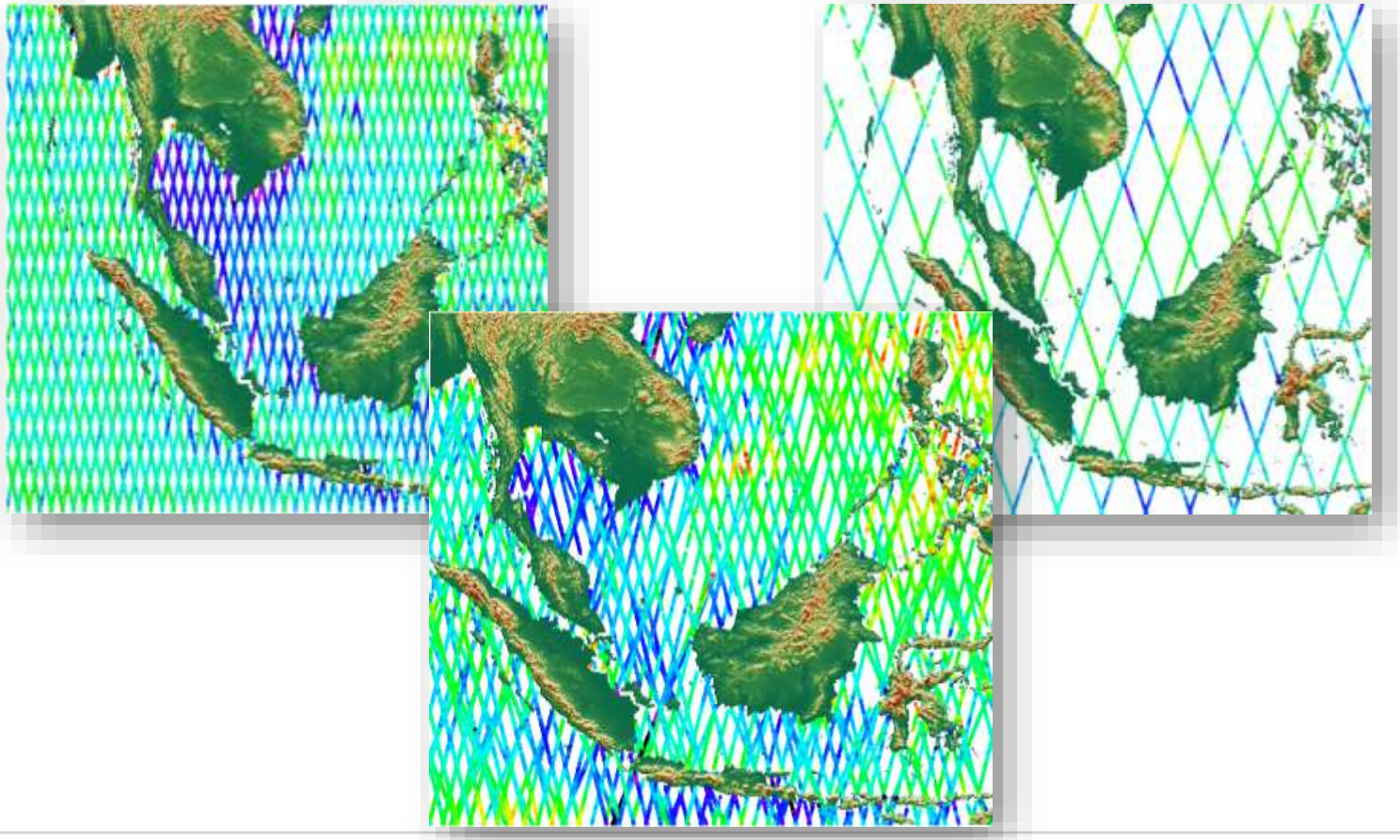
Parameter for Altimeter Corrections

***Crossover Minimization**: Topex-class as a standard surface

DATA & METHODS

EnviSat

Jason-2



Crossover Adjustment & Multi-mission Altimeter

EnviSat + Jason-2
(1 day data using 9 days moving window)

Tidal Data from DSMM

Data Verification

- **Altimetry data are exactly extracted at TG (IDW Method)**
- **Focus : Pattern, correlation & RMSE analysis**

Data Description:

Mission: TOPEX, Jason-1/2, ERS-1/2 EnviSat, Cryosat & Saral

Period : Jan 1993 to Dec 2015

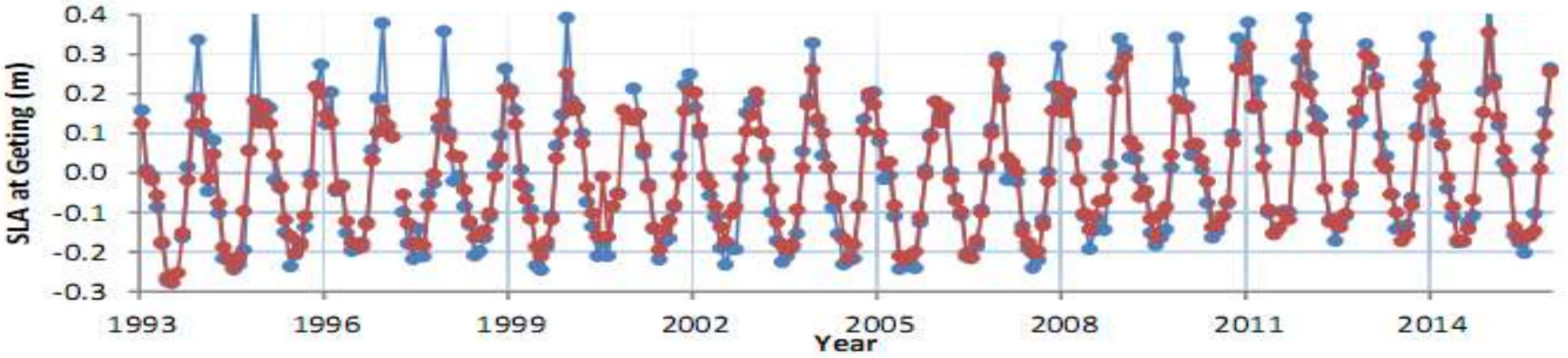
Tide Gauge : Geting, P. Tioman, Bintulu, K. Kinabalu

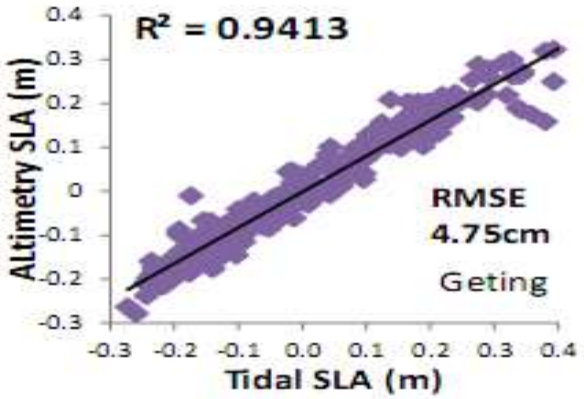
Period : Jan 1993 to Dec 2015

RESULTS & DISCUSSION

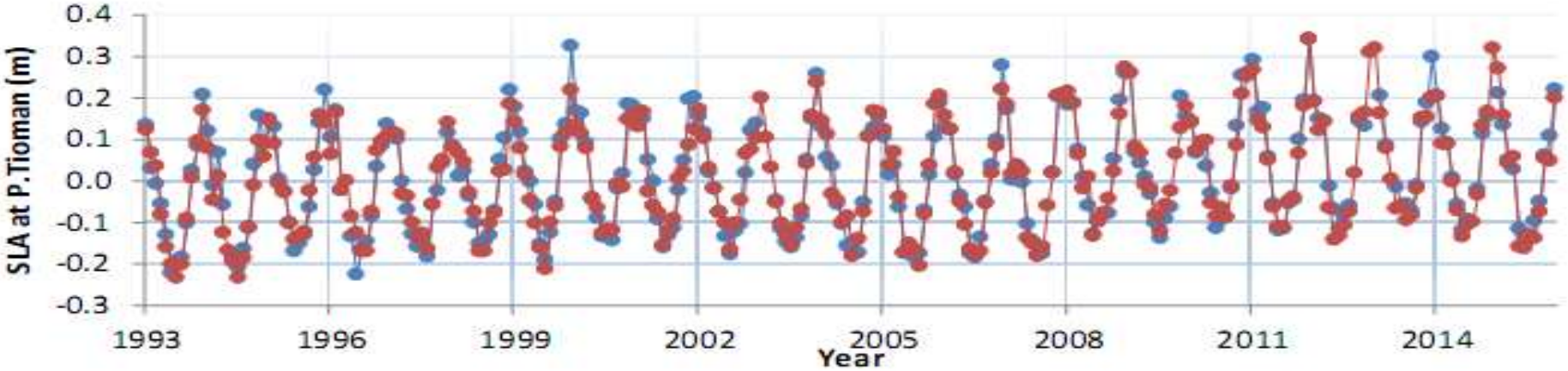
Data Verification: Altimetry (red) vs Tidal Data (blue)

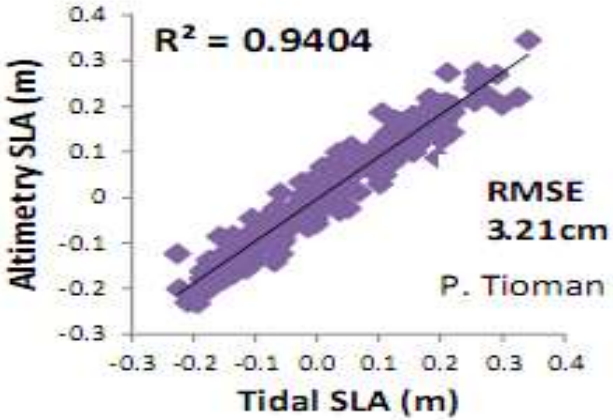
Tide Gauge Station at Geting





Tide Gauge Station at P. Tioman

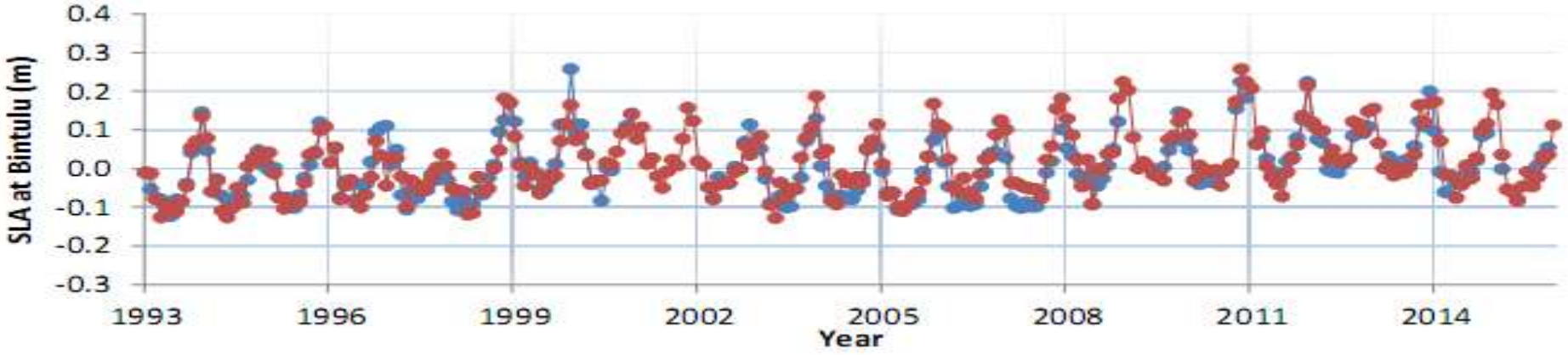


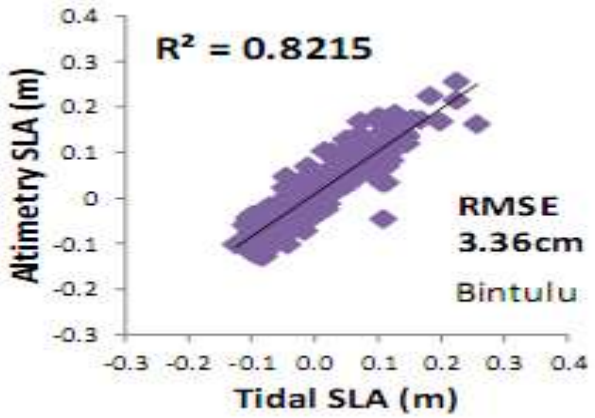


RESULTS & DISCUSSION

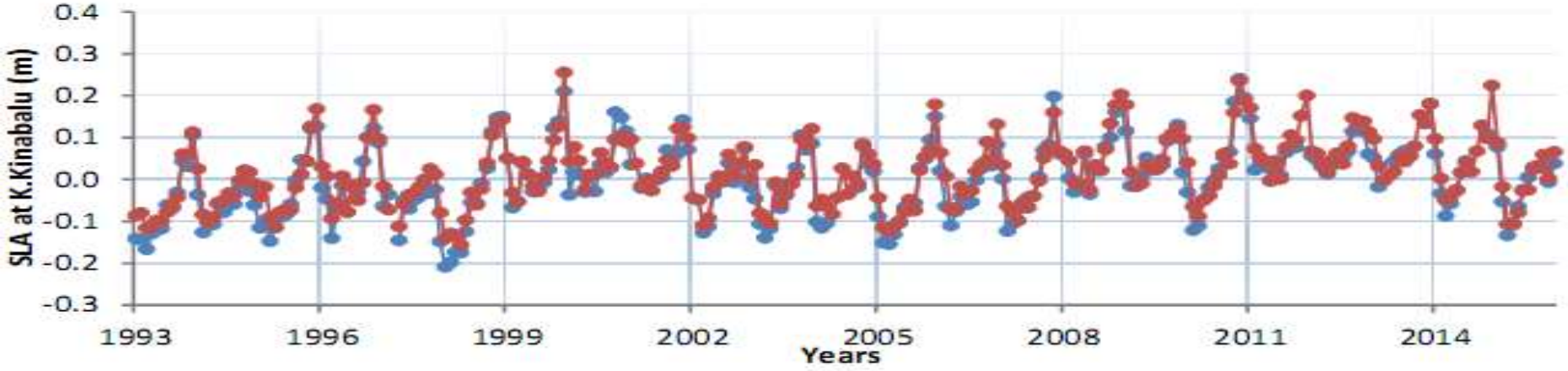
Data Verification: Altimetry (red) vs Tidal Data (blue)

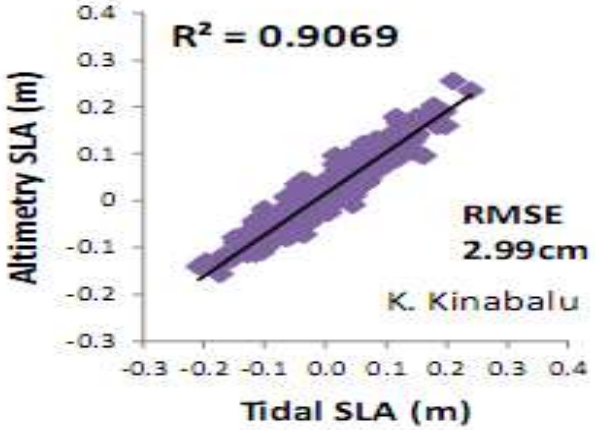
Tide Gauge Station at Bintulu





Tide Gauge Station at K. Kinabalu





RESULTS & DISCUSSION

Quantification of Sea Level Rate

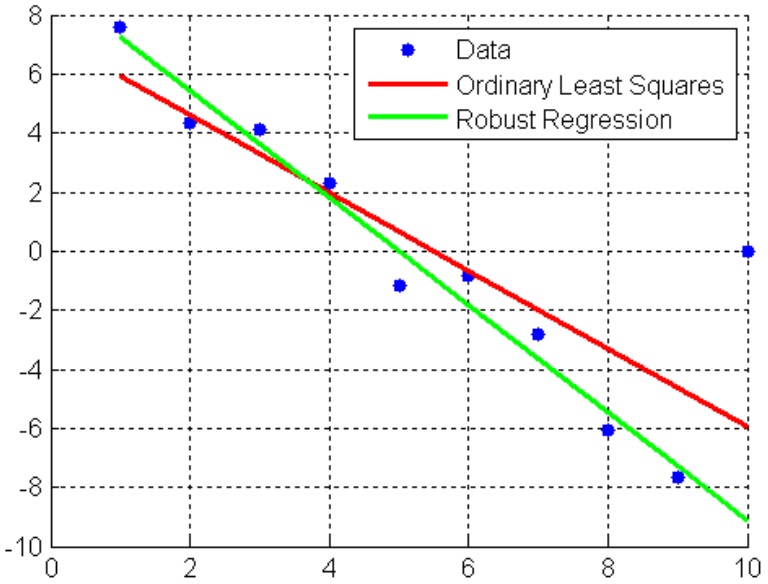
$$w_i = \begin{cases} (1-(u_i)^2)^2 & |u_i| < 1 \\ 0 & |u_i| \geq 1 \end{cases}$$

Sea Level Time Series Analysis:

- Robust fit regression analysis technique in MATLAB
- A standard statistical technique that simultaneously deals with solution finding and outliers detection is applied
- In this robust fit approach, a linear trend is fitted to the annual sea level time series of each station in an Iteratively Re-weighted Least Squares (IRLS) procedure (Holland and Welsch, 1977).

Where,

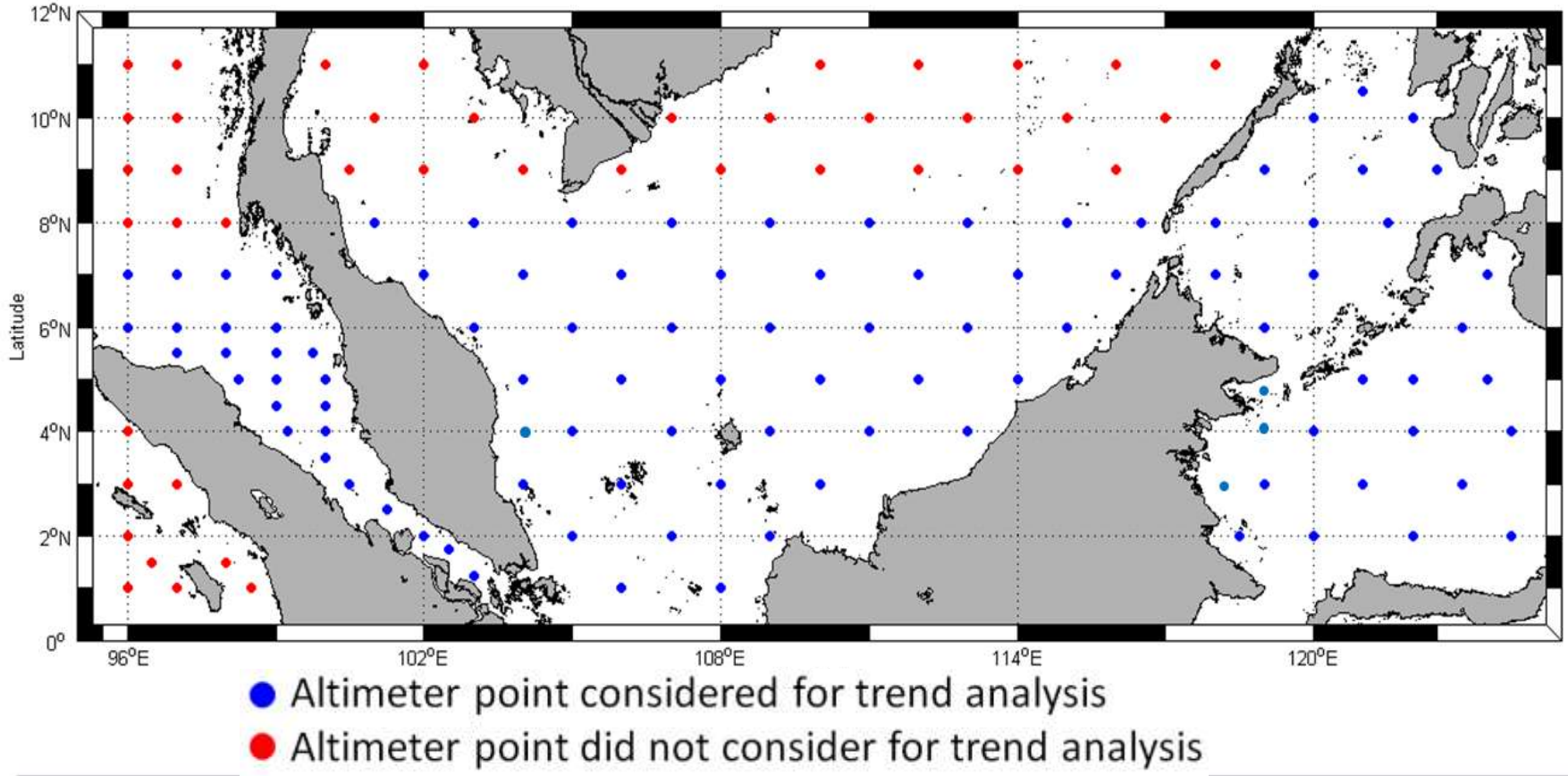
$$u_i = \frac{r_i}{K.S.\sqrt{1-h_i}}$$



The comparison between robust fit

RESULTS & DISCUSSION

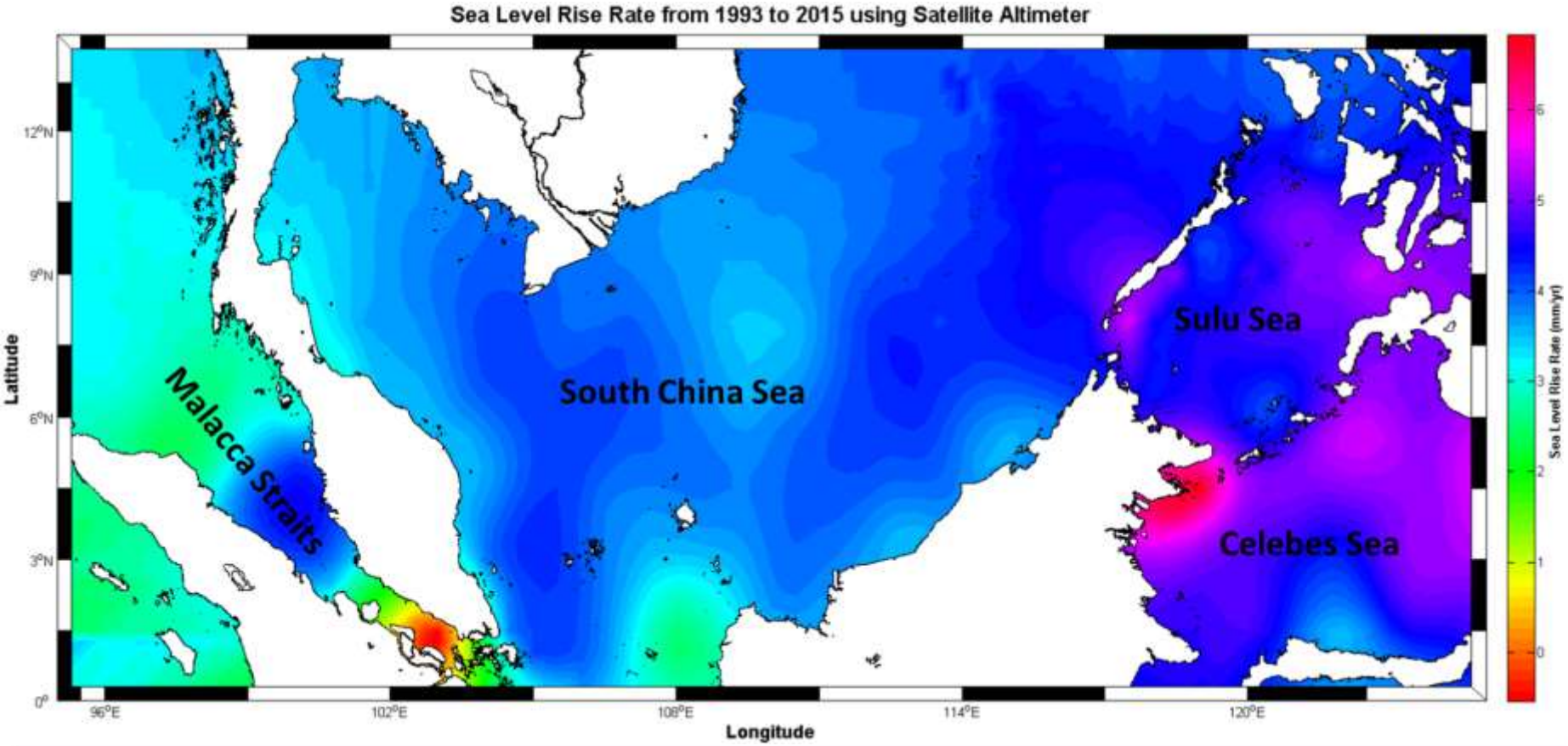
Points for Trend Analysis



The altimeter extracted points are focused for offshore or deep ocean areas because the residual of sea level anomaly increases closer to the coast due to the increased sea level variability in shallow water depth.

RESULTS & DISCUSSION

Map of Sea Level Trend over Malaysian Seas

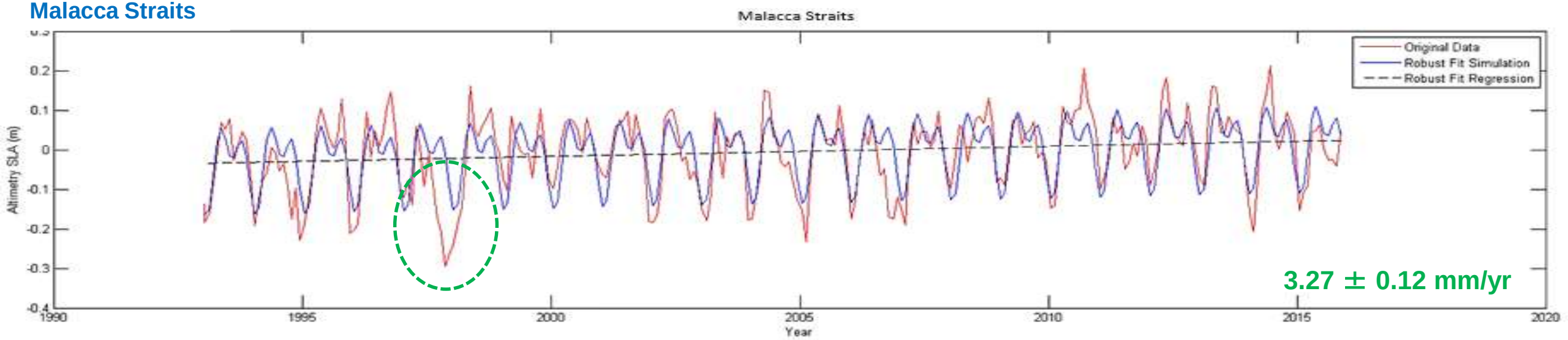


Region	Rate
Malacca Straits	1 to 4 mm/yr
South China Sea	3 to 5 mm/yr
Sulu Sea	3.5 to 5.5 mm/yr
Celebes Sea	3.5 to 6 mm/yr

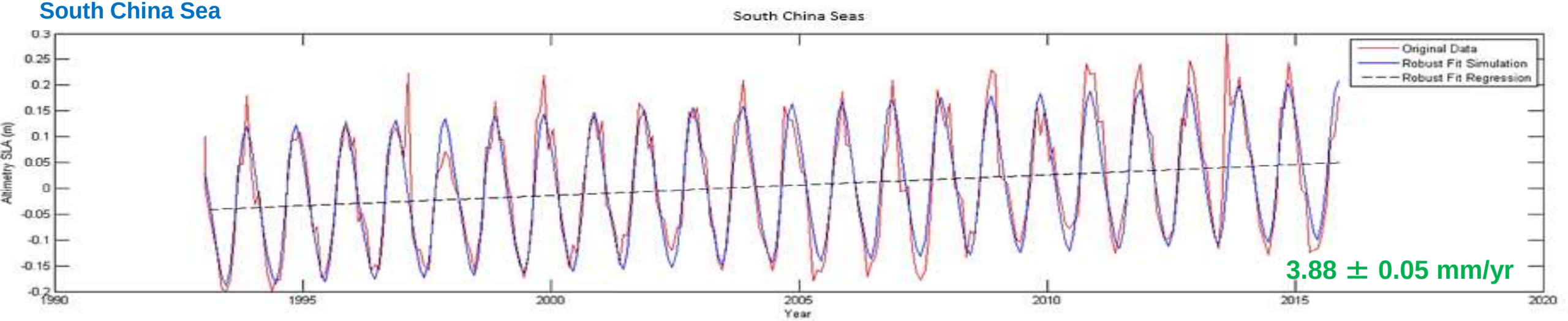
RESULTS & DISCUSSION

Time Series Analysis using Robust Fit Regression

Malacca Straits



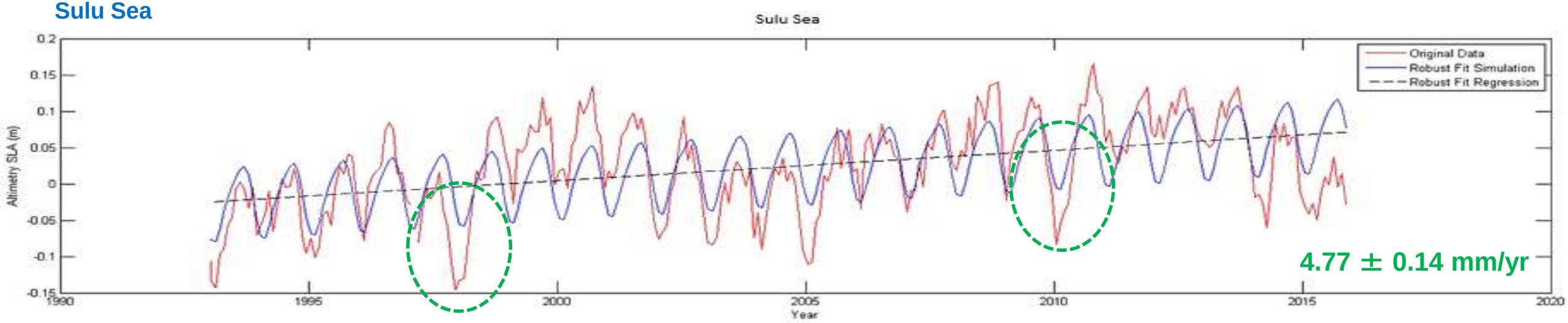
South China Sea



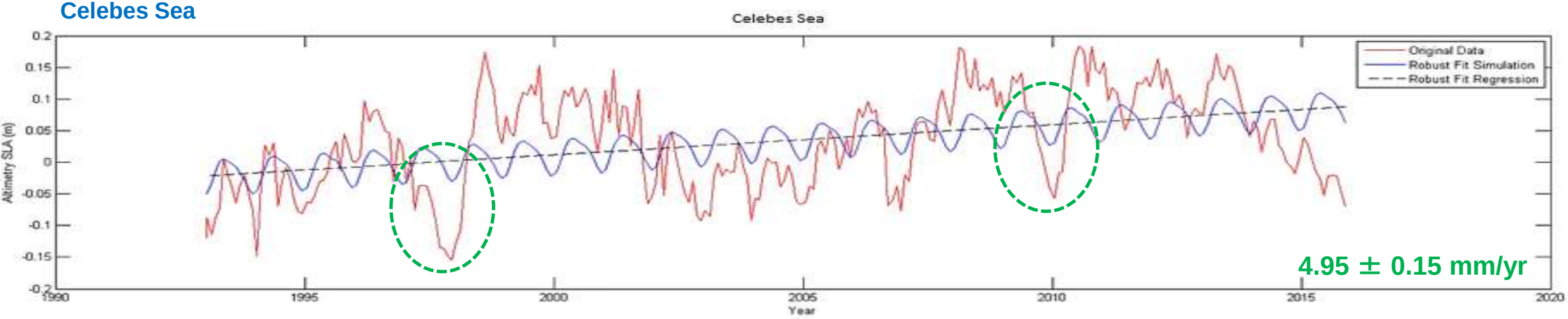
RESULTS & DISCUSSION

Time Series Analysis using Robust Fit Regression

Sulu Sea



Celebes Sea



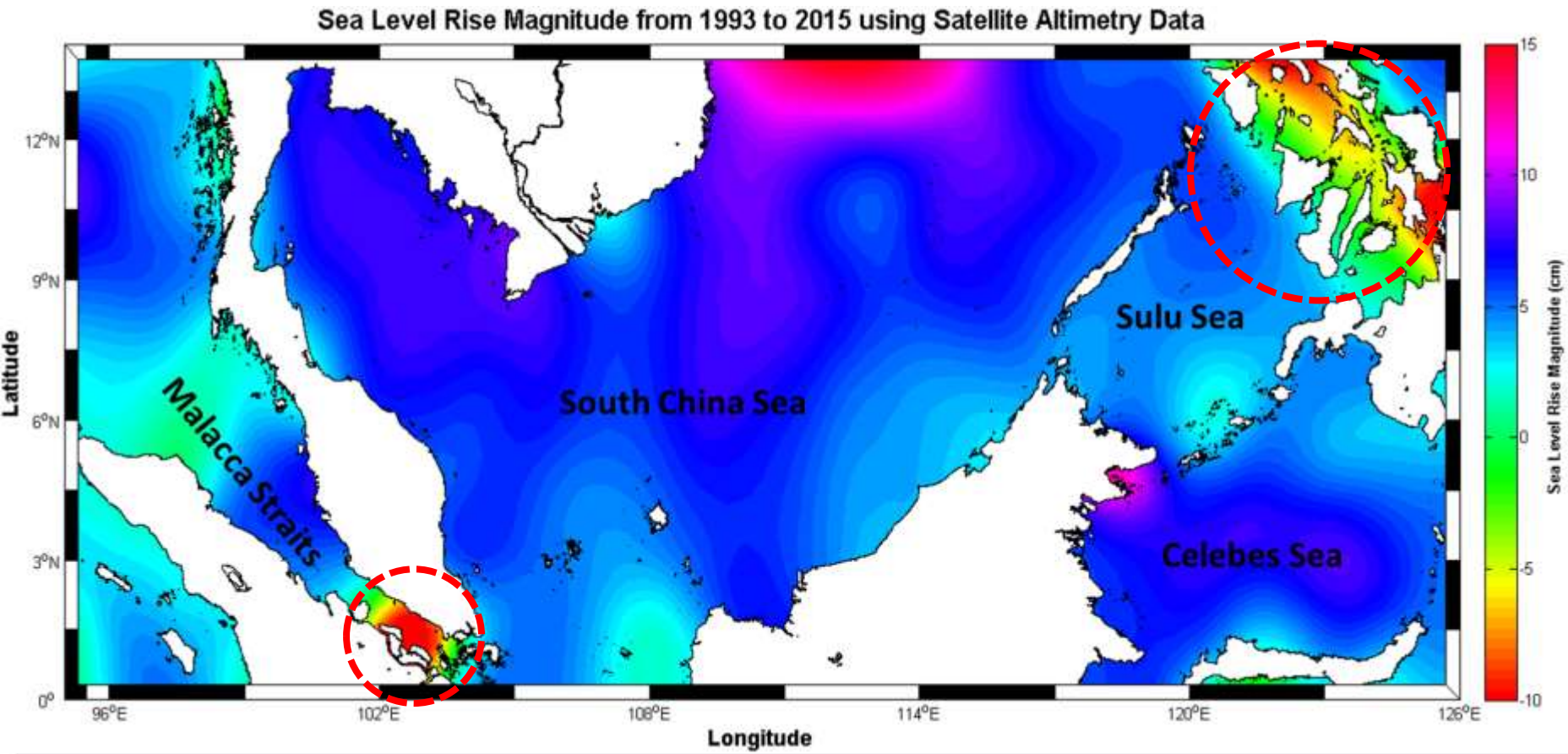
RESULTS & DISCUSSION

Group	Sea Level Rate (mm yr^{-1})
Malacca Straits	3.27 ± 0.12
South China Sea	3.88 ± 0.05
Sulu Sea	4.77 ± 0.14
Celebes Sea	4.95 ± 0.15
Total Average	**4.22 ± 0.12**

- The findings clearly show that the absolute sea level trend is rising and varying over the Malaysian seas with the rate of sea level varies and gradually increases from west to east of Malaysia.
- Highly confident and correlation level of the 23-years measurement data shows that the absolute sea level trend of the Malaysian seas has raised at the rate from 3.27 ± 0.12 mm yr^{-1} to 4.95 ± 0.15 mm yr^{-1} for the chosen sub-areas, with an overall mean of **4.22 ± 0.12 mm yr^{-1}**.

RESULTS & DISCUSSION

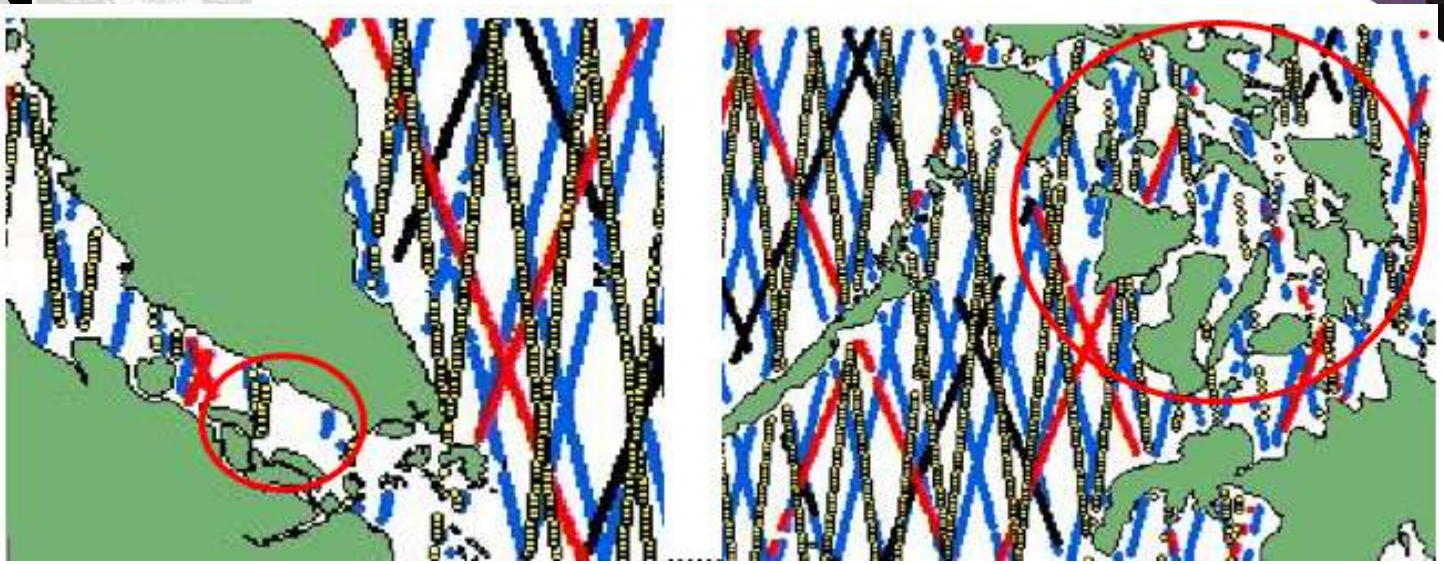
Magnitude of Sea Level over Malaysian Seas



Range	2 to 10 cm

RESULTS & DISCUSSION

Satellite track of Cryosat-2 (yellow), Jason-1 (red), Jason-2 (black), and Saral (blue) while area concerned in the red circle in which around Malacca Straits (left) and Philippine archipelago (right)



In overall, the magnitude of sea level rise in the Malaysian seas is at about 0.053m from year 1993 to 2015.

Group	Sea Level Rise (m)
Malacca Straits	0.054
South China Sea	0.053
Sulu Sea	0.047
Celebes Sea	0.056
Total Average	0.053

SUMMARY REMARKS

From the techniques and processing methods presented in this study, with a data span from 1993 to 2015 using multi-mission satellite altimetry data, we can conclude that:

1) The absolute sea level trend is rising and varying over the Malaysian seas.

2) With an overall mean, the sea level rate has been rising at a rate of 4.22 +/- 0.12 mm/yr, for the region of Malaysia.

3) The magnitude of sea level is increasing at about 5.3cm (overall mean) over Malaysian seas from 1993 to 2015.

Special Thanks to:

1) Universiti Teknologi Malaysia and Ministry of Higher Education (MOHE) under the FRGS Fund, Vote Number R.J130000.7827.4F706.

2) Land Surveyors Board of Malaysia