Positive decadal change in interannual Sea Level variability in the Bay of Bengal

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Abstract

In this study, we have investigated the decadal change in interannual Sea Level anomaly (SLA) of the Bay of Bengal (BoB) using observed satellite altimeter data and a linear, continuously, and stratified (LCS) model. A rapid increase in SLA during the 2010-19 decade is observed compared to the 2000-09 decade throughout the Spring, Summer, Autumn, and Winter seasons. In order to explain the observed variability, We have executed some numerical experiments using LCS model. The significant change in Ekman pumping and equatorial forcing drives the change in decadal SLA along the western bay of Bengal. The contribution of forcing due to the boundary of the western BoB and Eastern BoB including the Andaman and Nicobar islands is not notable.

Keywords: `Sea Lvel Anomaly`, Decadal Change

2010 MSC: 00-01, 99-00

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1. Introduction

2. Data and Model

2.1. Observed Data

We have used daily satellite altimeter observation for the period of 2000-2019 period for our study. The resolution of the satellite altimeter data is 0.25^o x 0.25^o. More details can be found from this URL `https://cds.climate.`

[⋆]Fully documented templates are available in the elsarticle package on CTAN.

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copernicus.eu/cdsapp#!/dataset/satellite-sea-level-global?tab=overview In order to calculate the SLA, we subtracted the long term mean from the daily data.

We have also used O

2.2. Ocean Model

In our study, we have used a linear, continuously, stratified (LCS) model to explain the detailed dynamics of SLA, which is a simple wind driven model. The vertical solution of the LCS model is consist of the sum of 10 normal modes, which are estimated based on density profile of [1]. The defined region of this model is from 30^o E-120^oE and 30^oS-30^oN with the horizontal resolution of 0.1^o x 0.1^o. In this model, the nonlinear terms like horizontal and vertical advection terms have been not taken into account to maintain the linearity in the model. No slip closed boundary condition has been used in the model.

Land-sea masking of the model is evaluated using the topography of modified Etopo2 ([2] for the Indian Ocean. Continental shelf regions with the water depth of less than 200 m has been removed from the model. The The Gulf of Mannar area and Pacific ocean has been masked out from the model domain.

Model simulation has been done for the period of 1991-2019 using ERA5 ([3]) forcing. The ERA5 data description is available here https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels?tab=overview . In this study, model outputs from january 1998 to December 2016 has been used for detailed analysis.

2.3. Numerical Experiments

In order to determine the role of different parameters on the SLA, we have done some numerical experiments using the LCS, named as LCSCR, based on previously discussed wind forcing only. There are three types of experiments has been done using the special boundary conditions and linear damper as discussed in [4, 5, 6]. First experiment is related to absence of WBoB local wind by allowing allowing coastal Ekman flow to pass through the boundary using modified no-slip boundary condition $(u_n = v_n = 0)$. The modified boundary condition (MBC) is :

$u_n = n.v_n = -n.k * F_n/f$; (1a)

$v_n = k * n.v_n = 0.$ (1b)

In the above equation, n is the unit vector normal to the boundary, F_n is the wind-stress vector, k is the unit vector directed upward, f is Coriolis frequency, u_n and $v_n$are velocity components perpendicular and parallel to the boundary. During the first experiment, the above MBC are applied along WBoB ranging from 6.5^{o}N to 20^{o}N. After subtracting the first experiment solution from the LCSCR, we named it LCS$_{WB}$, which represents the influence of WBoB local winds forcing on SLA. Similarly, the second experiment have been done along the eastern and northern boundaries of BoB including Andaman and Nicobar islands (EBoB) and after subtracting the solution from the LCSCR solution, we named it LCS$_{EB}$, representing the forcing response only due to above remove coastal winds.

The third experiment has been done using a linear damper between 6.5^{o}N to 6.5^{o}S to stop equatorial wave response to BoB. After subtracting the above solution from the LCSCR, we name it LCS$_{EIO}$, which represents only the influence of equatorial wind on the SLA. And, by subtracting all these three solutions LCS$_{WB}$, LCS$_{EB}$, LCS$_{EIO}$ from the LCSCR, the response from interior BoB is quantified and named as LCS$_{BI}$.

2.4. Validation of model

[7, 8, 5, 6] discussed previously about detailed validation of LCSCR. In this manuscript, we have done a statistical validation like Correlation and RMSE of LCSCR in the simulation of altimeter observed SLA in the BoB region using 400dayslow-pass filter as well. The correlation plot of fig 2 for unfiltered and 400dayslow-pass filtered altimeter observed SLA and LCSCR shows good correlation of values greater than 0.3 and low RMSE value as well. In the figure 3, the correlation of ocean current and LCSCR has been shown. Strong positive correlation has been shown in the WBoB between unfiltered as well as filtered ocean current and LCSCR for both U and V current.

3. Observed and Model simulated climatology of Interannual SLA and Current in BoB

In this section, altimeter observed and LCS model simulated interannual SLA variability during summer season La Nina years between 2000-2019 along WBoB has been discussed. In order to quantify interannual variability of SLA, seasonal variability has been removed using 400 days low-pass time series $4'th$ order Butter-worth filter to eliminate the variability associated with less than annual time scale (400 days).

we have analyzed the decadal changes in the observed interannual SLA and current in BoB, especially the WBoB. In order to describe interannual variability of SLA and current along WBoB, regions have been divided into three boxes, which includes northern BoB (NBoB; 85^{o}E-90^{o}E, 17^{o}N,21^{o}N), central BoB (CBoB, 80^{o}E-85^{o}E,14^{o}N-16^{o}N) and southern BoB (SBoB, 80^{o}E-85^{o}E, 10^{o}N-13^{o}N). All three regions are shown in all figures. To specify the decadal variability in BoB SLA and current, we have subtracted 10 years of climatology of 2000-2009 (ClimA) from climatology of 2010-2019 (ClimB).

During the Spring season, WBoB shows positive SLA for 2010-19 climatology for both observed SLA and LCSCR while it was less positive during 2000-09. Amplitude is high for the observed SLA compare to the LCSCR. Poleward current has been observed for the 2000-09 and 2010-19 climatology along the WBoB while our model also showed the same. The decadal change during this season shows positive observed SLA

4. Observed and Model simulated Decadal Change of Interannual SLA and Current in BoB

5. Dynamics behind the decadal change of Interannual SLA and Current

References

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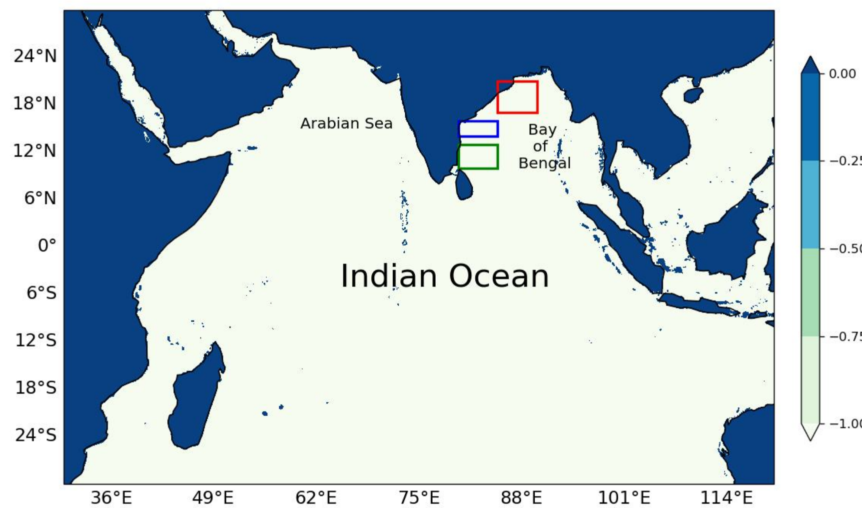


Figure 1:

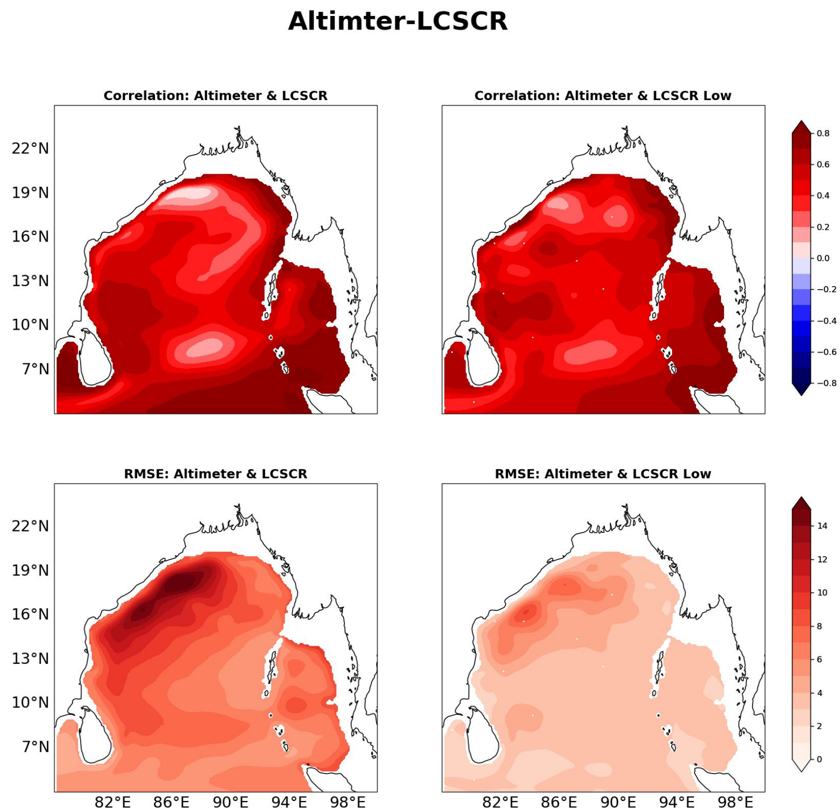

Altimter-LCSCR
Correlation: Altimeter & LCSCR
Correlation: Altimeter & LCSCR Low
RMSE: Altimeter & LCSCR
RMSE: Altimeter & LCSCR Low
22°N
19°N
16°N
13°N
10°N
7°N
82°E
86°E
90°E
94°E
98°E
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
14
12
10
8
6
4
2
0

Figure 2:

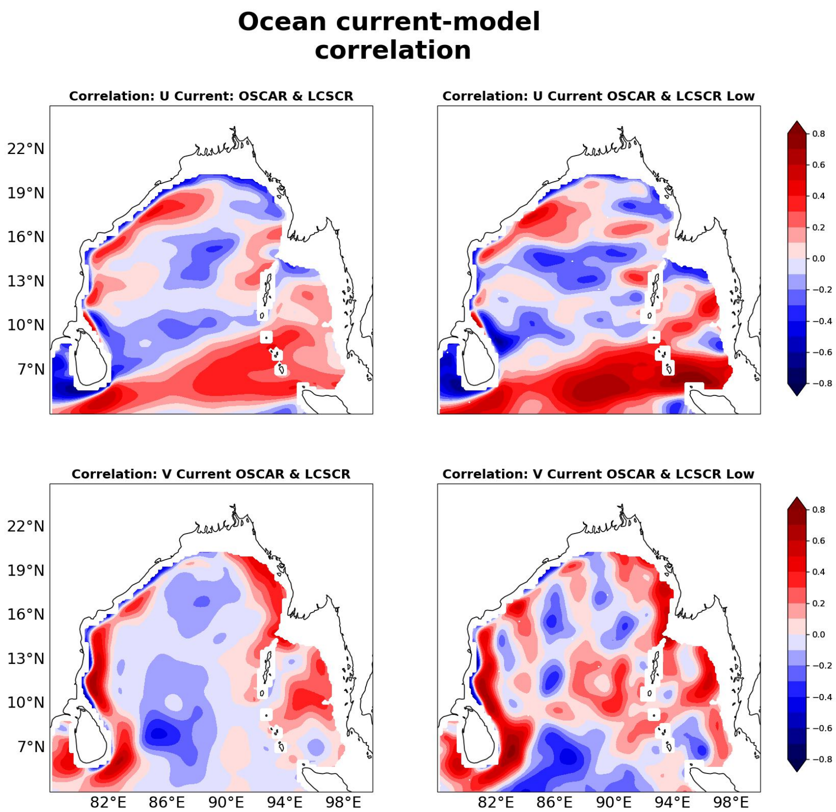
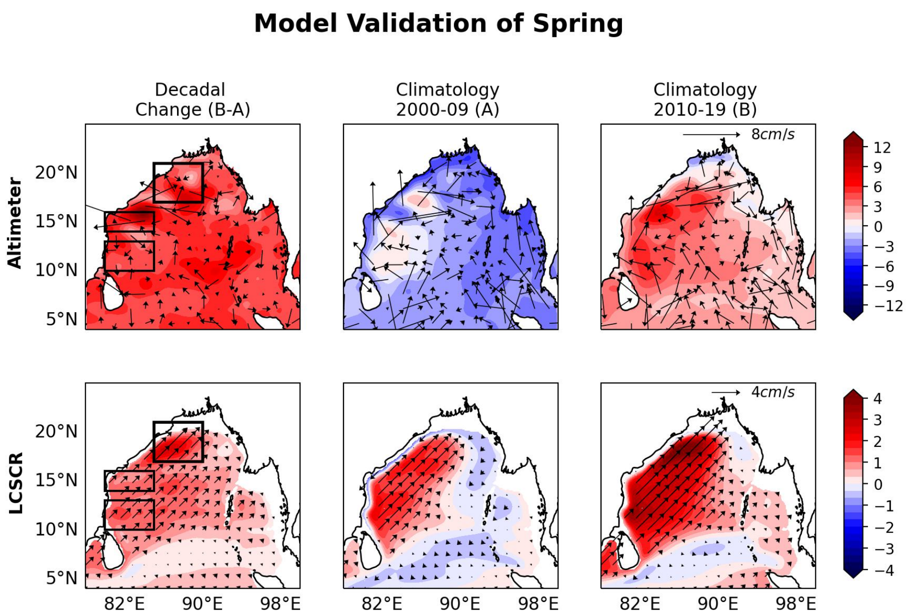

Ocean current-model correlation
Correlation: U Current: OSCAR & LCSCR
Correlation: U Current OSCAR & LCSCR Low
Correlation: V Current OSCAR & LCSCR
Correlation: V Current OSCAR & LCSCR Low
22°N
19°N
16°N
13°N
10°N
7°N
82°E
86°E
90°E
94°E
98°E
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8

Figure 3:



Model Validation of Spring
Decadal
Change (B-A)
Climatology
2000-09 (A)
Climatology
2010-19 (B)
Altimeter
LCSCR
8cm/s
4cm/s
20°N
15°N
10°N
5°N
82°E
90°E
98°E
12
9
6
3
0
−3
−6
−9
−12
4
3
2
1
0
−1
−2
−3
−4

Figure 4:

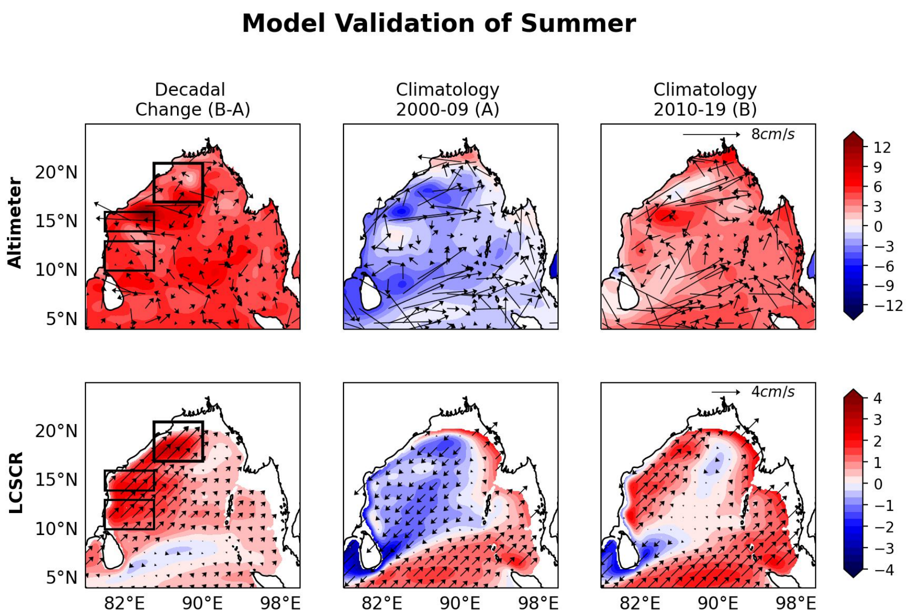

Model Validation of Summer
Decadal
Change (B-A)
Climatology
2000-09 (A)
Climatology
2010-19 (B)
8cm/s
4cm/s
Altimeter
LCSCR
20°N
15°N
10°N
5°N
82°E
90°E
98°E
12
9
6
3
0
−3
−6
−9
−12
4
3
2
1
0
−1
−2
−3
−4

Figure 5:

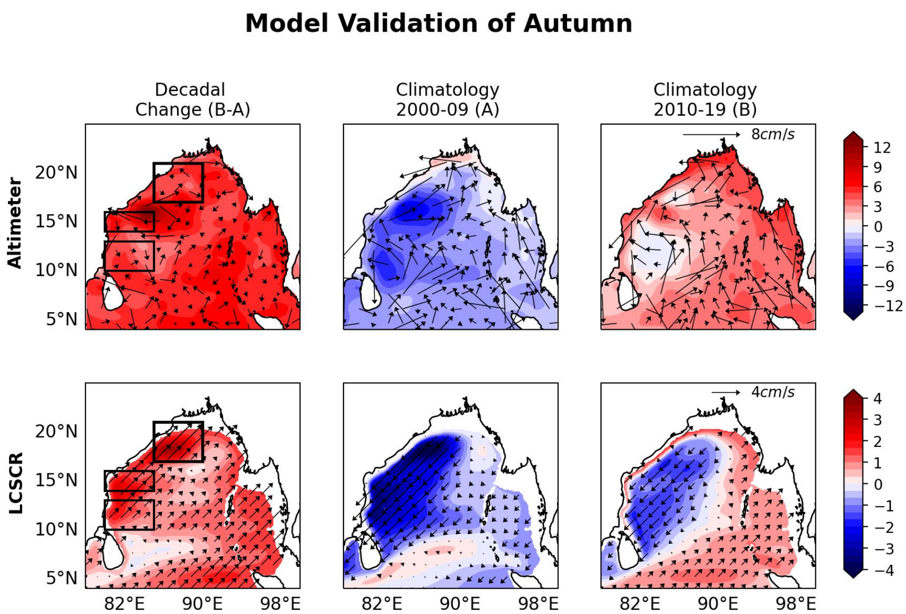
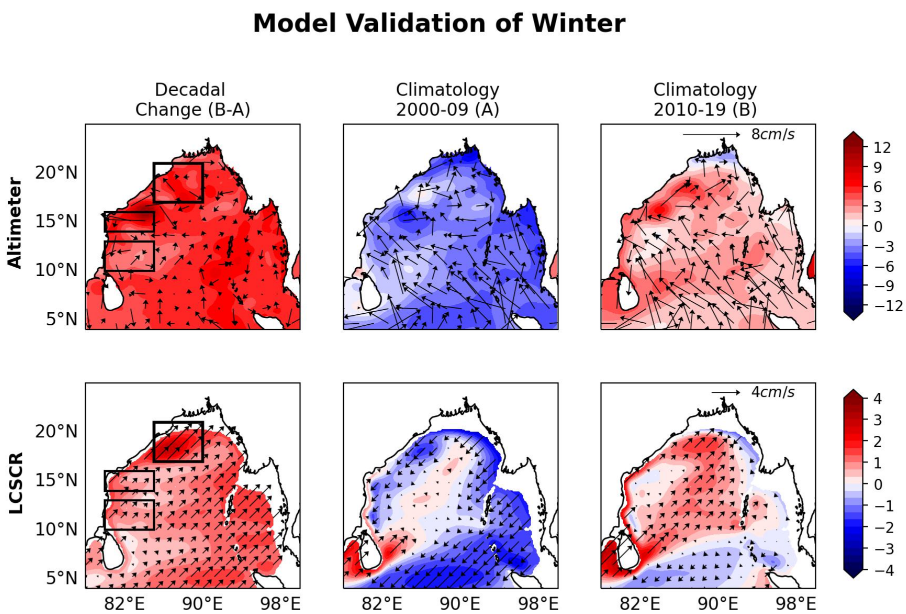
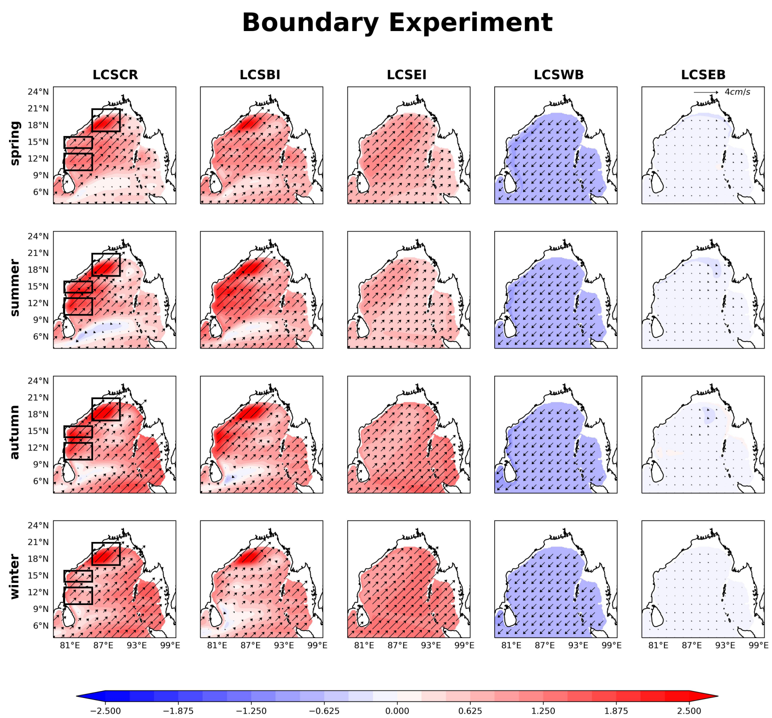

Model Validation of Autumn
Decadal Change (B-A)
Climatology 2000-09 (A)
Climatology 2010-19 (B)
Altimeter
LCSCR
8cm/s
4cm/s
20°N
15°N
10°N
5°N
82°E
90°E
98°E
12
9
6
3
0
−3
−6
−9
−12
4
3
2
1
0
−1
−2
−3
−4

Figure 6:



Model Validation of Winter
Decadal
Change (B-A)
Climatology
2000-09 (A)
Climatology
2010-19 (B)
8cm/s
4cm/s
Altimeter
LCSCR
20°N
15°N
10°N
5°N
82°E
90°E
98°E
12
9
6
3
0
−3
−6
−9
−12
4
3
2
1
0
−1
−2
−3
−4

Figure 7:



Boundary Experiment
LCSCR
LCSBI
LCSEI
LCSWB
LCSEB
4cm/s
spring
summer
autumn
winter
24°N
21°N
18°N
15°N
12°N
9°N
6°N
81°E
87°E
93°E
99°E
−2.500
−1.875
−1.250
−0.625
0.000
0.625
1.250
1.875
2.500

Figure 8:

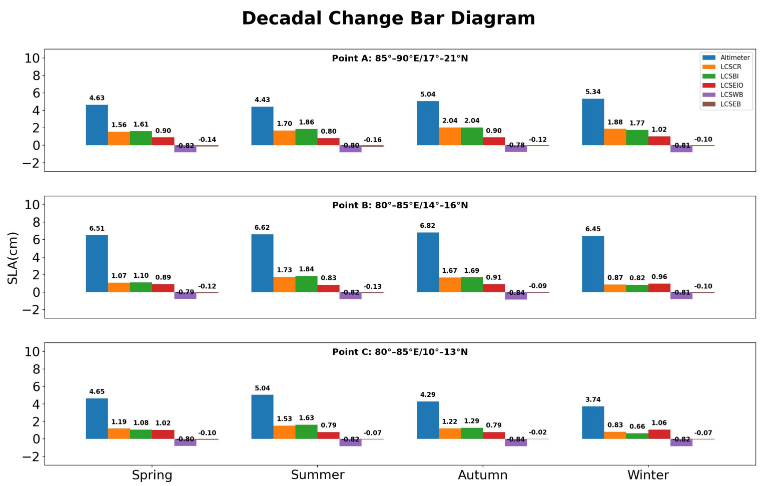

Decadal Change Bar Diagram
Point A: 85°–90°E/17°–21°N
Point B: 80°–85°E/14°–16°N
Point C: 80°–85°E/10°–13°N
Altimeter
LCSCR
LCSBI
LCSEIO
LCSWB
LCSEB
SLA(cm)
Spring
Summer
Autumn
Winter

Figure 9: