Technical Note ~~*Article*~~

Effect of Argo salinity drift since 2016 on the estimation of regional steric sea level change rates

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The supplementary figures show in details the steric sea level change in the 0–300 m, 300–1000 m depth ranges and within the Indian Ocean, the North Pacific and South Pacific, and the North Atlantic.

The supplementary tables display the halo-steric sea level rates in the above regions over the periods 2005–2015, 2016–2019, and 2005–2019 and the thermo-steric and total steric sea level rates over the period 2005–2019.

1. *Effect of salinity drift within the 0–300 m depth range*

Figures S1e and S1f display the non-seasonal variations of HSSL from 0 to 300 m and the corresponding linear trends for different time intervals. The HSSL changes estimated from IPRC and BOA data both exhibit decreasing trends during 2016–2019, which are about -0.33 ± 0.15 mm/year and -0.24 ± 0.14 mm/year, respectively. Conversely, over the same period, the estimates obtained from the SIO data show an increasing trend, with a value of about 0.30 ± 0.16 mm/year. In the period 2005–2015, unaffected by significant salinity drift since 2016, the HSSL changes estimated from all three datasets (SIO, IPRC, and BOA) show a decreasing trend. The estimates obtained from the SIO and IPRC data are similar, around -0.18 ± 0.04 and -0.20 ± 0.04 mm/year, respectively. The estimated trend from the BOA data is around -0.10 ± 0.04 mm/year, which is slightly smaller than that from the SIO data. As a combined result of the periods 2005–2015 and 2016–2019, the estimated HSSL changes derived from the three datasets all exhibit a decreasing trend during 2005–2019 (see Table S1).

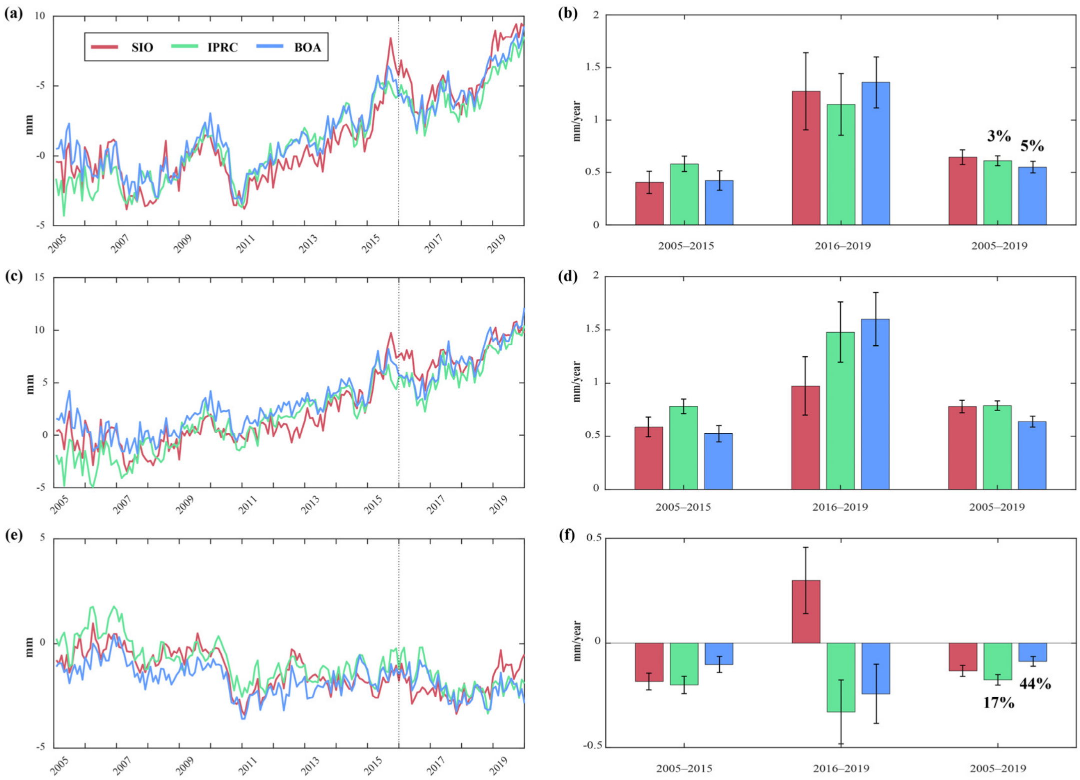

Figure S1. Non-seasonal variations of the near-global mean SSL at 0–300 m depth from 2005 to 2019. (**a**) Time series of total SSL (sum of thermosteric and halosteric sea level) change; (**b**) Linear trend of SSL over different time periods; (**c**) Same as (a) but for the thermosteric sea level change; (**d**) Same as (b) but for the thermosteric sea level change; (**e**) Same as (a) but for the halosteric sea level change; (**f**) Same as (b) but for the halosteric sea level change.

By comparing the above situations, one can find a slight difference between HSSL rates estimated by these three datasets during 2005–2019, with a value of -0.05 ± 0.04 mm/year (IPRC vs. SIO) and 0.04 ± 0.04 mm/year (BOA vs. SIO), respectively. The impact resulting from different data processing strategies adopted by the three Argo data centers are -0.02 ± 0.06 mm/year (IPRC vs. SIO) and 0.08 ± 0.06 mm/year (BOA vs. SIO), respectively. Consequently, the impact of salinity drift in the IPRC data (since 2016) on the estimation of the HSSL rate is about -0.03 ± 0.07 mm/year during 2005–2019, which accounts for 17% of the corresponding HSSL rate (-0.18 ± 0.04 mm/year). Similarly, the salinity drift in the BOA data affects its estimate by about -0.04 ± 0.07 mm/year, accounting for 44% of the corresponding HSSL rate (-0.09 ± 0.02 mm/year).

Table S1. The HSSL, TSSL, and total SSL rates (in mm/year) estimated from SIO, IPRC and BOA data during different time periods, at the depth of 0–300 m.

Data	HSSL			TSSL	SSL
	2005–2015	2016–2019	2005–2019	2005–2019	2005–2019
SIO	-0.18 ± 0.04	0.30 ± 0.16	-0.13 ± 0.03	0.78 ± 0.01	0.65 ± 0.02
IPRC	-0.20 ± 0.04	-0.33 ± 0.15	-0.18 ± 0.02	0.79 ± 0.01	0.61 ± 0.03
BOA	-0.10 ± 0.04	-0.24 ± 0.14	-0.09 ± 0.02	0.64 ± 0.01	0.55 ± 0.02

Furthermore, Figures S1a and S1c depict the non-seasonal changes of the total SSL and TSSL from 2005 to 2019, respectively. Based on the results from least squares fitting, we find that during this period, the HSSL rate estimated by the IPRC data accounts for 19% of the estimated total SSL rate, and the HSSL rate estimated by BOA data accounts for 12% of the estimated total SSL rate (see Table S1). When considering the impact of salinity drift since 2016 on the HSSL rate estimates, we can observe that the significant drift in salinity data only affects the total SSL rate estimation by about 3% for the IPRC products and by about 5% for the BOA products. Here we note that due to the large uncertainty in the impact of salinity drift in this depth range, the reliability of these results still needs to be verified by other independent observations.

2. *Effect of salinity drift within the 300–1000 m depth range*

Figure S2e illustrates the non-seasonal change of HSSL in the depth range of 300–1000 m, while Figure S2f presents the corresponding linear trend over different time intervals. The HSSL changes estimated from all the three datasets show decreasing trends during 2016–2019, and the HSSL decreasing trends estimated from the IPRC and BOA datasets are more significant than that estimated from the SIO dataset. These trends are -0.63 ± 0.17 mm/year (IPRC), -0.75 ± 0.13 mm/year (BOA), and -0.32 ± 0.11 mm/year (SIO), as shown in Table S2. Moreover, the HSSL changes estimated from all three datasets shows weak increasing trends during 2005–2015 (see Table S2). For a longer period 2005–2019, the HSSL estimated by SIO data demonstrates a weak increasing trend, about 0.07 ± 0.02 mm/year. However, the estimated HSSL changes from the IPRC and BOA datasets exhibit weak decreasing trends, which are close to each other with a value of around -0.04 ± 0.03 mm/year.

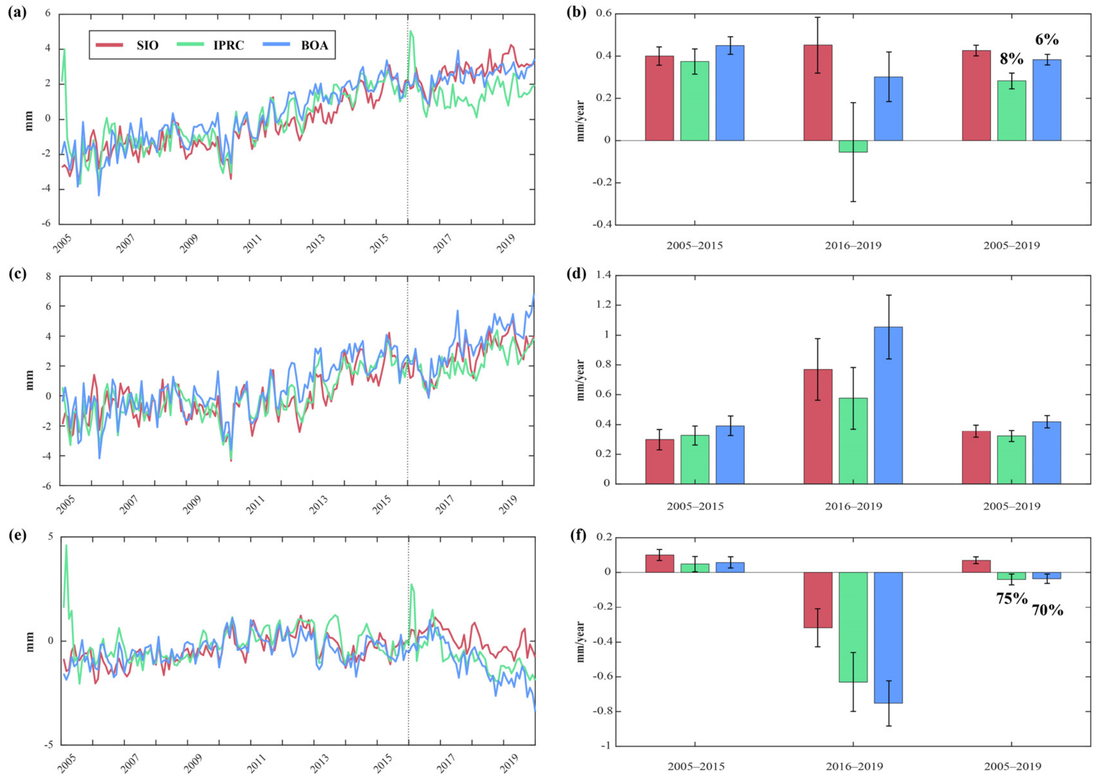

Figure S2. Non-seasonal components of the near-global mean SSL variations at 300–1000 m depth from 2005 to 2019. (**a**) Time series of the total SSL change; (**b**) Linear trend of SSL over different time periods; (**c**) Same as (a) but for the thermosteric sea level change; (**d**) Same as (b) but for the thermosteric sea level change; (**e**) Same as (a) but for the halosteric sea level change; (**f**) Same as (b) but for the halosteric sea level change.

Based on the above results, the difference between the estimated HSSL rates from the IPRC and BOA datasets and the estimates from the SIO dataset is about -0.11 ± 0.04 mm/year during 2005–2019. Among them, the differences resulting from different data processing strategies adopted by these three data centers are about -0.05 ± 0.05 mm/year (IPRC vs. SIO) and -0.04 ± 0.05 mm/year (BOA vs. SIO), respectively. Therefore, the impact of the salinity drift (since 2016) in the IPRC and BOA datasets on the estimation of the HSSL rates is about -0.06 ± 0.06 mm/year and -0.07 ± 0.06 mm/year from 2005 to 2019, respectively. This influence contributes 75% to the estimated HSSL rate for the IPRC data and 70% to the estimated HSSL rate for the BOA data.

Table S2. The HSSL, TSSL, and total SSL rates (in mm/year) estimated from SIO, IPRC and BOA data for different time periods, at the depth of 300–1000 m.

Data	HSSL			TSSL	SSL
	2005–2015	2016–2019	2005–2019	2005–2019	2005–2019
SIO	0.10 ± 0.03	-0.32 ± 0.11	0.07 ± 0.02	0.36 ± 0.04	0.43 ± 0.03
IPRC	0.05 ± 0.04	-0.63 ± 0.17	-0.04 ± 0.03	0.32 ± 0.04	0.28 ± 0.04
BOA	0.06 ± 0.03	-0.75 ± 0.13	-0.04 ± 0.03	0.42 ± 0.04	0.38 ± 0.02

Furthermore, Figures S2a and S2c demonstrate the non-seasonal changes in TSSL and total SSL at the 300–1000 m depth range. The least-squares fitting results indicate that the TSSL and total SSL rates estimated from IPRC data are 0.32 ± 0.04 mm/year and 0.28 ± 0.04 mm/year during 2005–2019 (see Table S2). The contribution of the HSSL rate to the total SSL rate is approximately 11%. The estimated TSSL and total SSL rates from the BOA data are about 0.42 ± 0.04 mm/year and 0.38 ± 0.02 mm/year, respectively. The HSSL rate contributes about 9% to the total SSL rate. Considering the effect of salinity drift on the HSSL rate estimation and the contribution of the HSSL rate to the total SSL rate, we can find that the salinity drift in the IPRC data has an effect of about 8% on the estimated total SSL rate, while this effect is around 6% for the BOA data. It should be noted that the uncertainty of the salinity data drift effects in this depth range is comparable to the value itself, which suggests that the assessment is affected by the notable noise and further analysis might be needed in the future study.

3. *Effect of salinity drift within the Indian Ocean*

Figure S3e displays the non-seasonal HSSL variations within the Indian Ocean. The corresponding HSSL rates for different periods in this region are shown in Figure S3f. During 2016–2019, the SIO data estimate shows an increasing trend of about 1.01 ± 0.54 mm/year. However, the estimated HSSL change derived from the IPRC and BOA datasets both show decreasing trends, around -0.63 ± 0.55 mm/year and -1.03 ± 0.55 mm/year, respectively. From 2005 to 2015, the HSSL change estimated from the SIO data shows an increasing trend, around 0.16 ± 0.09 mm/year. However, both the IPRC and BOA data estimates show decreasing trends, approximately -0.18 ± 0.11 m/year and -0.14 ± 0.13 mm/year, respectively. For a longer period 2005–2019, the HSSL change estimated from the SIO data shows an increasing rate, while those derived from the IPRC and BOA datasets show decreasing rates (see in Table S3).

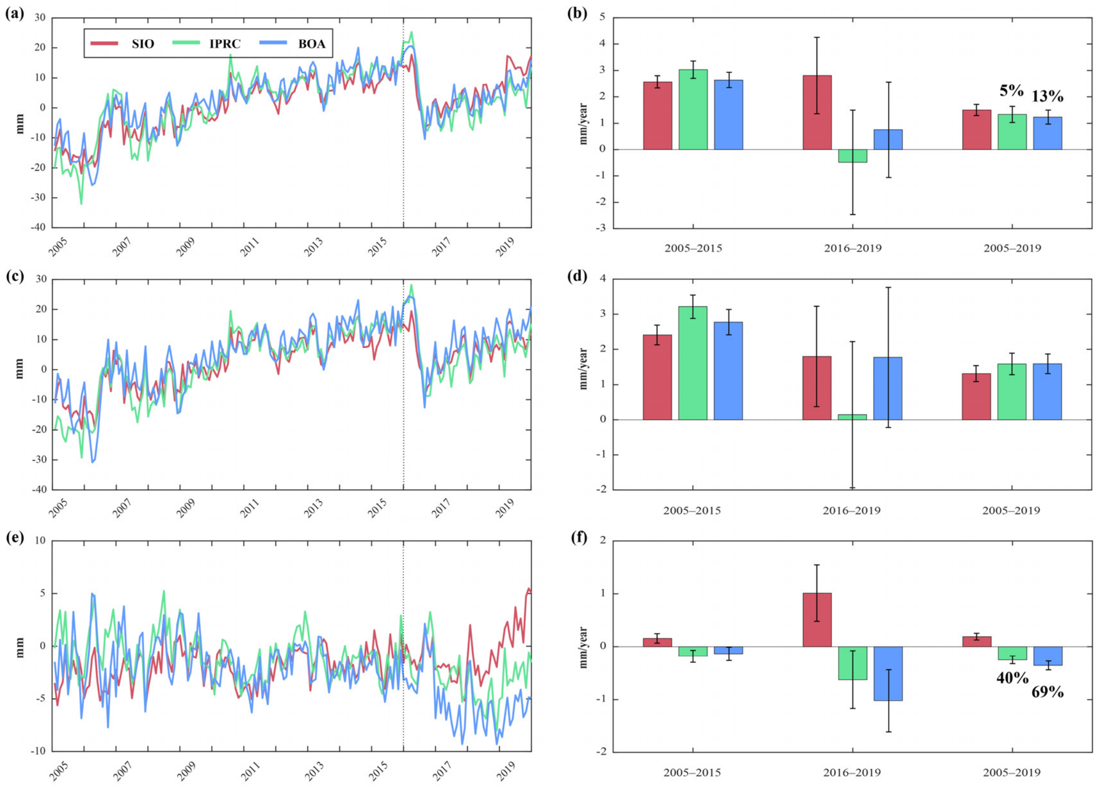

Figure S3. Non-seasonal variations of the regional mean SSL in the Indian Ocean from 2005 to 2019. (**a**) Time series of the total SSL change; (**b**) Linear trend of SSL for different time periods; (**c**) Same as (a) but for the thermosteric sea level change; (**d**) Same as (b) but for the thermosteric sea level change; (**e**) Same as (a) but for the halosteric sea level change; (**f**) Same as (b) but for the halosteric sea level change.

Based on the above results, during the period 2005–2019, the HSSL rates estimated by the IPRC and BOA data differed from those estimated by the SIO data by approximately -0.44 ± 0.09 mm/year (IPRC) and -0.55 ± 0.10 mm/year (BOA), respectively. And the contribution of different data processing methods used by various institutions is around -0.34 ± 0.14 mm/year (IPRC vs. SIO) and -0.30 ± 0.16 (BOA vs. SIO) mm/year, respectively. Therefore, the impact of salinity drift in the IPRC and BOA datasets (since 2016) on the estimation of the 2005–2019

HSSL rate within this region is around -0.10 ± 0.17 mm/year and -0.25 ± 0.17 mm/year, respectively.

Table S3. The HSSL, TSSL and total SSL rates estimated from the SIO, IPRC and BOA data in different time periods within the Indian Ocean (in mm/year).

Data	**HSSL**			**TSSL**	**SSL**
	2005–2015	2016–2019	2005–2019	2005–2019	2005–2019
SIO	0.16 ± 0.09	1.01 ± 0.54	0.19 ± 0.06	1.31 ± 0.23	1.50 ± 0.21
IPRC	-0.18 ± 0.11	-0.63 ± 0.55	-0.25 ± 0.07	1.59 ± 0.30	1.34 ± 0.30
BOA	-0.14 ± 0.13	-1.03 ± 0.59	-0.36 ± 0.08	1.59 ± 0.28	1.24 ± 0.26

The impact of salinity drift accounts for about 40% (IPRC) and 69% (BOA) of the HSSL rate within the Indian Ocean. Figures S3e and S3f show that 86% (for IPRC data) and 82% (for BOA data) of the SSL rate is contributed by TSSL, with the remaining 14% (for IPRC data) and 18% (for BOA data) contributed by HSSL. Meanwhile, the salinity drift affects the estimated SSL rate by about 5% for IPRC data and about 13% for BOA data. However, it can be noted that the uncertainty of the salinity drift effect in IPRC data is larger than the value itself, and the uncertainty of the salinity drift effect in BOA data is generally comparable to the value itself, so the reliability of the quantitative assessment is affected by the notable noise and might need to be further analyzed in the future study.

4. Effect of salinity drift within the North Pacific and South Pacific

Figures S4e and S5e illustrates the non-seasonal HSSL variations in the North Pacific and South Pacific, respectively. Within these two regions, the HSSL rates corresponding to different time periods are shown in Figures S4f and S5f. One can observe that the 2016–2019 HSSL rates estimated from the IPRC data are generally consistent with the SIO data estimates, both in the South Pacific and North Pacific. However, there is an obvious downward bias between the HSSL time series estimated from the IPRC data and that from the SIO data. In addition, there is also a significant difference between the HSSL time series estimated from the IPRC data and that from the SIO data for the period 2005–2015. This makes it difficult to tell whether the effect of the IPRC salinity data drift within the South Pacific and North Pacific is significant by using merely the segment analysis method.

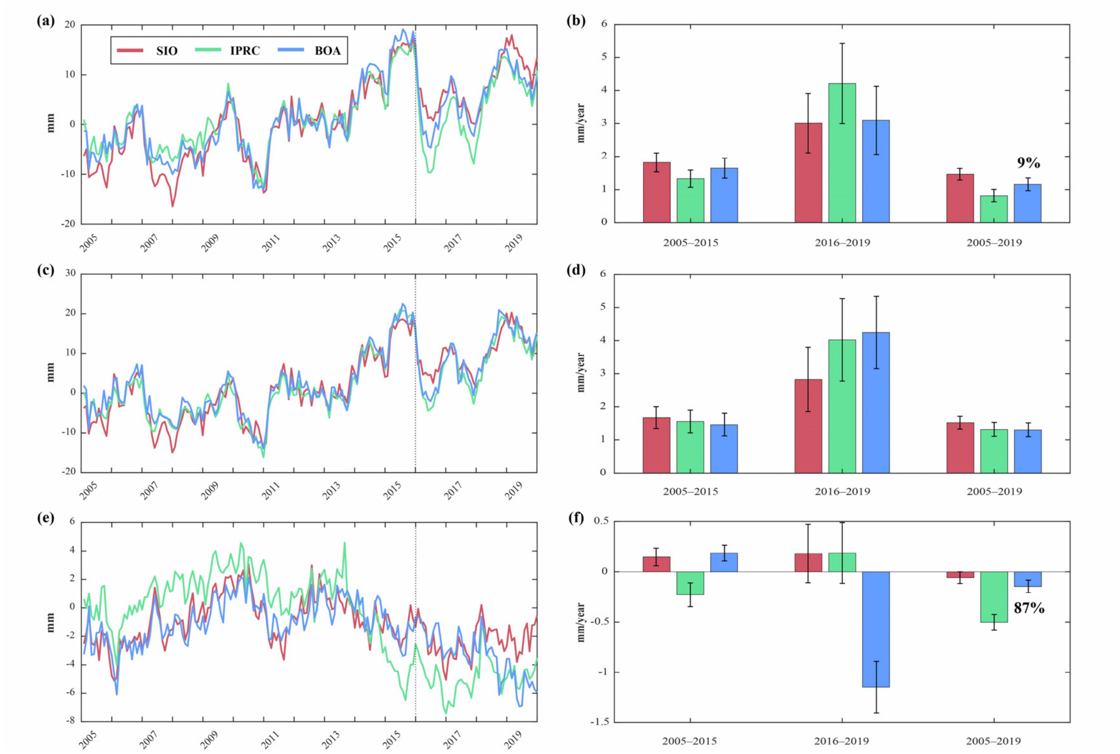

Figure S4. Non-seasonal variations of the regional mean SSL in the South Pacific from 2005 to 2019. (**a**) Time series of the total SSL change; (**b**) The linear trend of SSL over different time periods; (**c**) Same as (a) but for the thermosteric sea level change; (**d**) Same as (b) but for the thermosteric sea level change; (**e**) Same as (a) but for the halosteric sea level change; (**f**) Same as (b) but for the halosteric sea level change.

Additionally, it is also difficult to reliably determine the effect of the BOA salinity data drift within the North Pacific using the segmented analysis method. From Figures S5e and S5f, it can be seen that there is a downward bias between the HSSL time series estimated from the BOA data during 2017–2019 and that from the SIO data, resulting in a smaller increasing rate in the 2016–2019 HSSL estimated from the BOA data (compared to that from the SIO data). Moreover, there is a downward bias between the 2005–2006 HSSL time series estimated by the BOA data and those from the SIO data. The BOA results show a relatively smaller decreasing rate in 2005–2015 HSSL compared to the SIO time series. Therefore, it should be reasonable to conclude that the decreasing rate of the 2005–2019 HSSL estimated by the BOA data is generally consistent with that estimated by the SIO data.

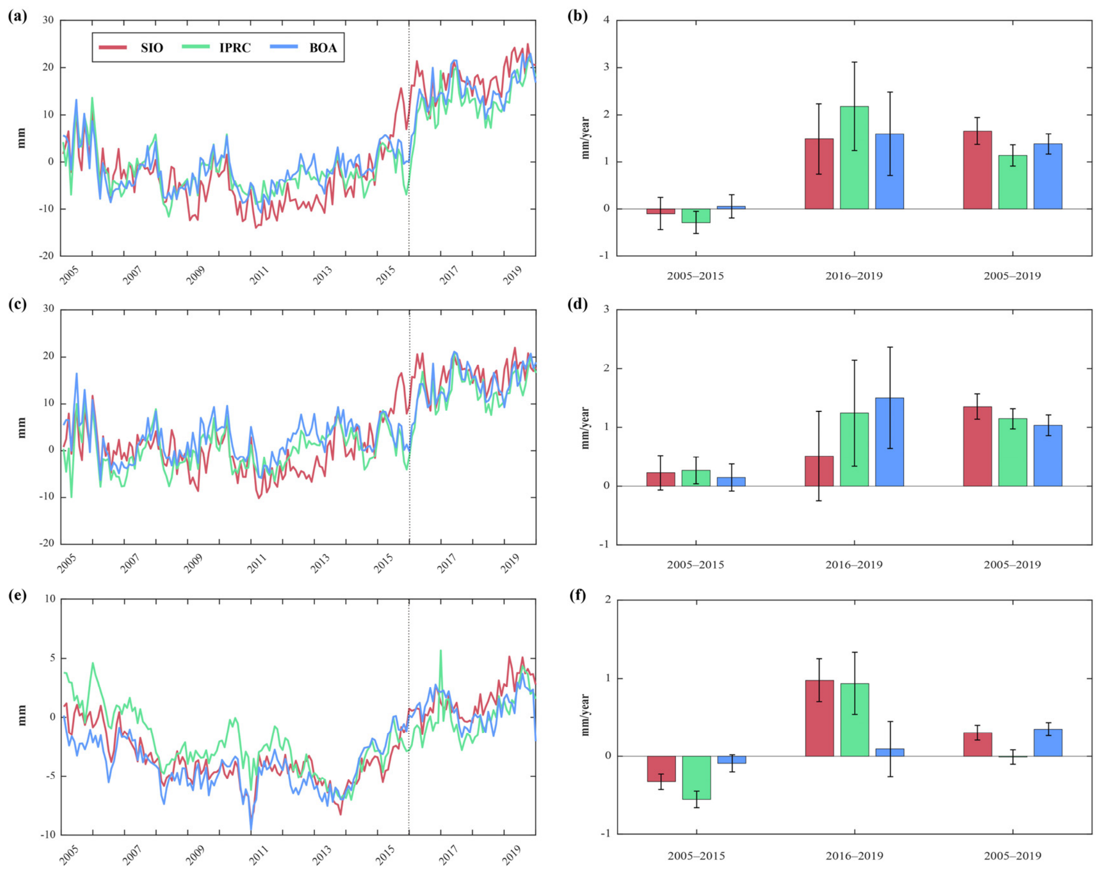

Figure S5. Non-seasonal variations of the regional mean SSL in the North Pacific from 2005 to 2019. (**a**) Time series of the total SSL change; (**b**) Linear trend of SSL over different time periods; (**c**) Same as (a) but for the thermosteric sea level change; (**d**) Same as (b) but for the thermosteric sea level change; (**e**) Same as (a) but for the halosteric sea level change; (**f**) Same as (b) but for the halosteric sea level changes.

As shown in Table S4, during 2016–2019, the HSSL change estimated by the SIO data shows an increasing trend, with a value of about 0.18 ± 0.29 mm/year. However, the estimation of the BOA data shows an obvious decreasing trend, about -1.15 ± 0.26 mm/year. During the period 2005–2015, the HSSL changes estimated by these two datasets show increasing rates, about 0.15 ± 0.09 mm/year and 0.19 ± 0.08 mm/year, respectively. For a longer period 2005–2019, the HSSL changes estimated by SIO and BOA data both show decreasing rates, but the decreasing rate estimated by the BOA data is 0.09 ± 0.08 mm/year larger than that estimated by the SIO data. When assuming that the difference caused by the different data processing strategies adopted by these two data centers is about 0.04 ± 0.12 mm/year, the effect of BOA salinity data drift on their estimated HSSL rate is then about -0.13 ± 0.14 mm/year (87%) during 2005–2019. In addition, one can see from Figures S4a and S4c that the contribution of HSSL estimated from the BOA data to the total SSL rate is about 10% during 2005–2019. Therefore, the salinity drift (since 2016) in BOA data has an effect of about 9% on the estimated total SSL rate within the South Pacific. However, given that the uncertainty associated with the salinity drift effect is comparable to its value itself, the quantitative assessment here is also affect by the noise and needs further validation in the future study.

Table S4. The HSSL, TSSL, and total SSL rates (in mm/year) estimated from the SIO and BOA data in different time periods within the South Pacific.

Data	HSSL			TSSL	SSL
	2005–2015	2016–2019	2005–2019	2005–2019	2005–2019
SIO	0.15 ± 0.09	0.18 ± 0.29	-0.06 ± 0.06	1.52 ± 0.19	1.46 ± 0.18

BOA	0.19 ± 0.08	-1.15 ± 0.26	-0.15 ± 0.06	1.31 ± 0.21	1.16 ± 0.19

5. *Effect of salinity drift within the North Atlantic*

Figure S6e shows the non-seasonal HSSL variations within the North Atlantic. It can be seen that the HSSL changes estimated from the IPRC data in February 2005 and January 2016 show significant anomalies compared to the estimates in other months. These anomalies are probably caused by the drifts in IPRC salinity data at the 300–1000 m depth range of the eastern North Atlantic and the 300–2000 m depth range of the western North Atlantic. Meanwhile, these two salinity anomalies also affect the accuracy of the HSSL changes estimated by the IPRC data in the 300–1000 m and 1000–2000 m layers. In addition to the estimation from the IPRC data, within this region, the HSSL estimated by the BOA data shows a decreasing trend during 2016–2019, which is comparable to the SIO data estimates. However, the HSSL estimated from BOA data during 2005–2015 shows an increasing rate, which is also comparable to that obtained from the SIO data estimates. Therefore, it is difficult to tell whether the impact of the BOA salinity drift (since 2016) on its estimate of the 2005–2019 HSSL rate is significant by using only the segmented analysis method.

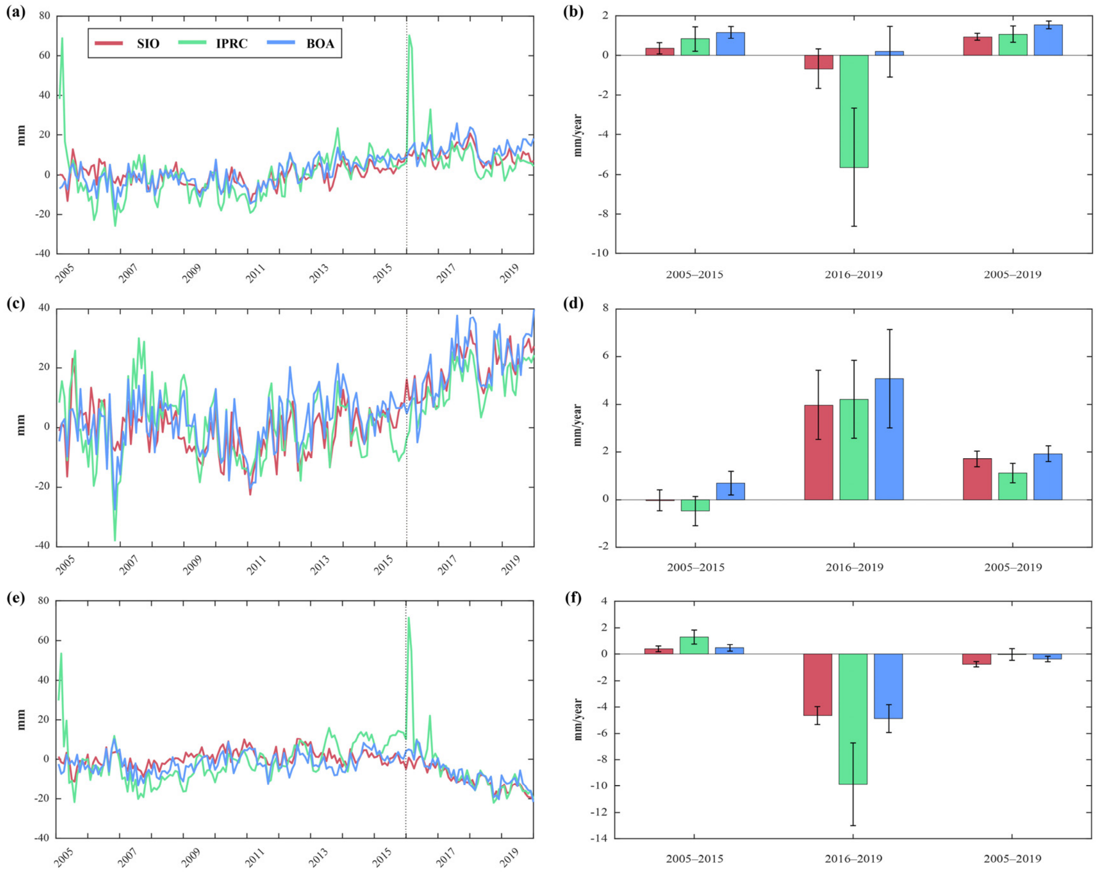

Figure S6. Non-seasonal variation of regional mean SSL in the North Atlantic from 2005 to 2019. (**a**) Time series of the total SSL change; (**b**) Linear trend of SSL over different time periods; (**c**) Same as (a) but for the thermosteric sea level change; (**d**) Same as (b) but for the thermosteric sea level change; (**e**) Same as (a) but for the halosteric sea level change; (**f**) Same as (b) but for the halosteric sea level change.