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Testing the validity of regional detail in global analyses of Sea surface temperature — the case of Chinese coastal waters

Yan Li[1*], Hans von Storch[2,3], Qingyyuan Wang[4] and Qingliang Zhou[5]

[1]National Marine Data and Information Service, Tianjin, People's Republic of China

[2]Institut für Küstenforschung, Helmholtz zentrum Geesthacht, Germany

[3]Ocean University of China, Qingdao, People's Republic of China

[4]Tianjin Meteorological Observatory, Tianjin, People's Republic of China

[5]Chinese Meteorological Administration, Beijing, People's Republic of China

Abstract. We have designed a method for testing the quality of multidecadal analyses of SST in regional seas by using a set of high-quality local SST observations. In recognizing that local data may reflect local effects, we focus on dominant EOFs of the local data and of the localized data of the analyses. We examine patterns, and the variability as well as the trends of the principal components. This method is applied to examine four different SST analyses, namely HadISST1, ERSST, COBE SST, and NOAA OISST. They are assessed using a newly constructed high-quality data set of SST at 26 coastal stations along the Chinese coast in 1960-2015 which underwent careful examination with respect to quality, and a number of corrections of inhomogeneities. The four gridded analyses perform by and large well, in particular since 1980. However, for the pre-satellite time period, before 1980, the analyses differ among each other and show some inconsistencies with the local data, such as artificial break points, periods of bias and differences in trends. We conclude that gridded SST-analyses need improvement in the pre-satellite time (prior to 1980s), by re-examining in detail archives of local quality-controlled SST data in many data-sparse regions of the world.

[*] Corresponding author. E-mail address: ly_nmdis@163.com

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1. Introduction

Sea surface temperature (SST) is a key parameter for climate change assessments. It is significantly associated with many atmospheric and oceanographic modes, such as Pacific Decadal Oscillation (PDO), El Niño/South Oscillation (ENSO), Indian Ocean Dipole (IOD), etc. (Saji et al., 1999, Mantua and Hare, 2002, Yeh and Kim, 2010). A number of extended historical observed SST products have been used in global climatological community (Boehme et al. 2014; Hirahara et al. 2014), as well as in the regional climate change, for example the China Seas, the Baltic Sea and North Sea (Belkin, 2009; Wu et al., 2012; Stramska and Bialogrodzka, 2015). However, historical SST datasets have large uncertainties in long-term trend patterns in some regions. For example, observed SST changes in the tropical Pacific are still controversial, depending on the different dataset and study period (Bunge & Clarke 2009). Vecchiga et al. (2008) indicate that the equatorial zonal SST gradient in the Pacific has intensified in Hadley Centre Sea Ice and Sea Surface Temperature (HadISST) but weakened in Extended Reconstructed SST (ERSST) from the nineteenth to twentieth centuries. Scientists utilized several different datasets, including the reconstructed and un-interpolated datasets, to study the SST variability in tropical area and the China Seas (Xie et al., 2010; Liu and Zhang 2013, Tokinaga et al., 2012). They found that there were larger uncertainties in estimate of SST warming patterns using different SST datasets. Thus, it is also necessary for comparing different SST products over the regional areas in detail.

Coastal marine ecosystems yield nearly half of the earth's total ecosystem goods and services (Costanza, 1997). Simultaneously, they are highly influenced by local factors, such as the anthropogenic land-based processes, fresh water discharge and local tidal mixing. An accurate assessment of the local SST variability is needed most in marine ecosystem-based management. Here, we mainly focus on three globally gridded SST datasets, that is, the HadISST1, ERSST, COBE SST (Rayner et al., 2003, Ishii et al., 2005, Smith et al., 2008, Hirahara et al., 2014). All of these datasets have been widely used in the regional and global climate change studies. In order to test the validity of gridded SST datasets on a coastal scale, SST records for the period of 1960-2015 at total 26 coastal hydrological stations along Chinese coast are used which have been homogenized by adjusting artificial breakpoints. We study the performance of these gridded SST datasets in the coastal waters by comparing to the in situ SST records which have been homogenized.

Thus, the remainder of this paper is structured as follows: Details on the observational and gridded data sets and methodology used in this study are given in Section 2. Section 3

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introduces the local homogenized SST time series along the Chinese coast (Li et al., 2018), which is used as a reference to compare the gridded data to. For adding confidence in the quality of this data set, these data are compared to independent data set of local air temperature data. The basic statistics of the local SST-data series are shown. Section 4 describes the results and comparisons with gridded SST datasets in the Chinese coastal waters. Further discussion and conclusion are given in Section 5.

2. Data and methodology

2.1. Data source

The SST records during 1960-2015 at the 26 sites of coastal hydrological stations along the Chinese coast have been assembled and homogenized, using meta data and the Penalized Maximal *t* (PMT) test (Li et al., 2018). Homogenized monthly mean surface air temperature (SAT) series from National Meteorological Information Center (NMIC) of China (Xu et al., 2013) and the gridded SAT from the latest version of the Climate Research Unit's (CRU) gridded high resolution (0.5 °×0.5 °) dataset CRU TS 3.24.01 for 1960-2015 (Harris et al., 2014) are used to investigate the consistency of homogenized SST data with the local SAT.

Four globally gridded SST datasets are used (see Table 1): (1) The 1 °×1 ° Hadley Center Sea Ice and Sea Surface Temperature monthly dataset (HadISST) (Rayner et al., 2003); (2) The 1 °×1 ° Centennial In Situ Observation-Based Estimates of the Variability of SST (COBE SST) (Hirahara et al., 2014); (3) 2 °×2 ° Extended Reconstructed Sea Surface Temperature version 4 (ERSST v4) for 1960-2015 (Smith et al., 2008). (4) NOAA Optimum Interpolation SST (OISST) version 2 with high spatial resolution of 0.25 °×0.25 ° for 1982-2015 (Reynolds et al. 2007).

Table 1. Global gridded SST datasets that are commonly used for climate studies

Dataset	Resolution	Period	Sources
ERSST v4	2 °x 2 °	1960-2015	http://www.ncdc.noaa.gov/oa/climate/research/sst/ERSST. v4.php
HadISST	1 °x 1 °	1960-2015	http://www.metoffice.gov.uk/hadobs/hadisst/data/download.html
COBE SST	1 °x 1 °	1960-2015	http://ds.data.jma.go.jp/tcc/tcc/products/elnino/cobesst/cobe-sst.html
OISST	$\frac{1}{4}$ °x$\frac{1}{4}$ °	1982-2015	http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.oisst.v2.html

2.2. Methodology

Statistical methods such as conventional empirical orthogonal function (EOF) (Kim et al., 1996, von Storch and Zwiers 1999), correlation analysis and linear trend analysis are performed. The significance of each trend has been tested with the Mann-Kendall test using Sen's slope estimates quantify trends (Sen, 1968). The tests were stipulated to operate with a probability for a false rejection of the null hypotheses (i.e., zero trend) of 5%. They are conducted with the implicit assumption that the data are serially independent. There are only weakly correlated but not really independent. Thus, the tests are "liberal", i.e., have tendencies for falsely rejecting too often the null hypothesis, when it is actually valid (von Storch and Zwiers, 1999). However, since the effect is relatively weak, given the small serial correlations, and since we have no results, which are close to the stipulated critical levels, we do as if the serial dependence is not of importance. However, this caveat should be kept in mind, when assessing the results.

3. The local homogenized SST records along the Chinese coast

The locations of the 26 coastal hydrological stations and the identified break points at each station are displayed in Fig. 1a and 1b. The majority of change points are caused by instrument change and station relocation, accounting for about 60.6% and 24.6% of the total change points. In our work, we consider annual mean values. Some analyses with seasonal mean values are also calculated, but these are not covered by our present account and merely summarized. The supporting evidences are provided by the Supplementary Online Material (SOM) in Appendix B.

The standard statistics derived from the data in the period of 1960-2015, that is, long-term mean, the standard deviation of annual means and the decadal trends are listed in Table 2. SSTs vary spatially along the Chinese coast, between about 11.5 ℃ in the north and 25 ℃ in the far south. The standard deviations are of the order of 0.50 ℃ throughout, with a maximum of 0.71 ℃ and a minimum of 0.43 ℃. The decadal trends vary between 0.13 ℃ per decade to 0.29 ℃ per decade. Table 1 also provides the long-term means of the homogenized data and of the raw (unhomogenized) data. The differences between the homogenized data and the raw data (last column) vary between -2.26 ℃ and 0.53 ℃. At most of the 26 stations, a downward correction has been found necessary – only at two stations (YWO and PTN) an upward change was stipulated, in one case no change of the mean and in the remaining 23 a downward or zero change.

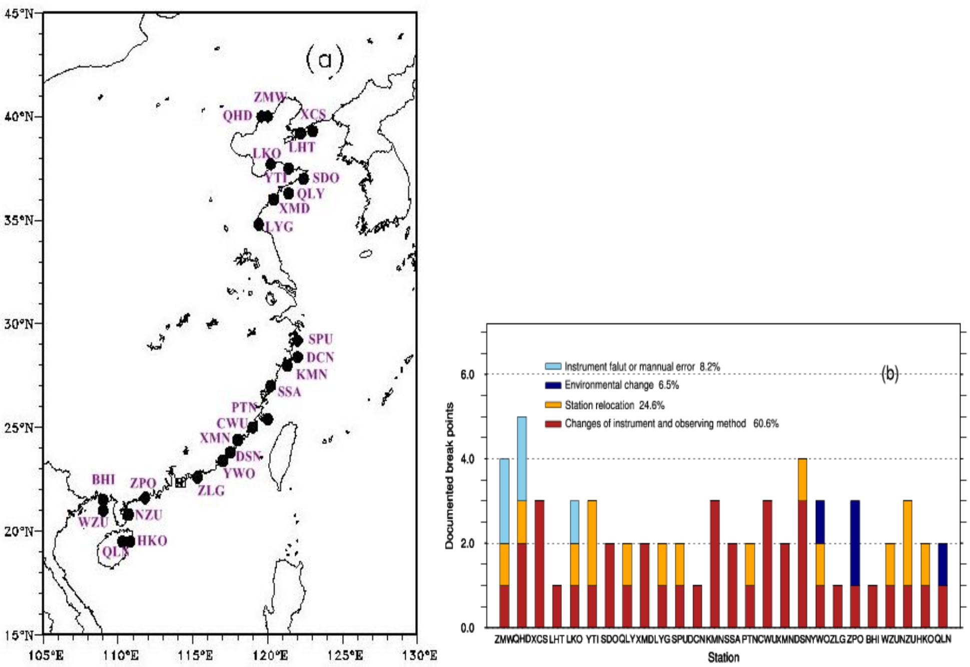

Figure 1. Locations of 26 coastal sites**(a)**, for which continuous monthly SST recordings are available and corrected by eliminating inhomogeneities. The identified breakpoints in individual SST stations from 1960-2015**(b)**.Results from Li et al. 2018.

Table 2. Statistics of the time series of the annual local homogenized SST, plus the differences to the raw data, which were used to construct the homogenized series (columns 7 and 8).

Station No.	Station name	Abbreviation	Mean Homogenized SST	Standard deviation	Trend (℃/10yrs)	Mean unhomogenized SST	Diff
1	Zhi Maowan	ZMW	11.50	0.53	0.17	11.75	-0.25
2	Qin Huangdao	QHD	12.21	0.59	0.26	12.32	-0.11
3	Xiao Changshan	XCS	11.54	0.71	0.29	11.73	-0.19
4	Lao Hutan	LHT	11.36	0.59	0.21	11.47	-0.11
5	Longkou	LKO	13.36	0.59	0.22	13.51	-0.15
6	Yantai	YTI	12.65	0.59	0.17	12.79	-0.14
7	Shidao	SDO	12.09	0.59	0.14	12.08	0.01
8	Qian Liyan	QLY	14.37	0.65	0.17	14.41	-0.04
9	Xiao Maidao	XMD	13.76	0.63	0.22	13.84	-0.08

10	Lian Yungang	LYG	14.85	0.57	0.21	14.94	-0.08
11	Shipu	SPU	17.41	0.65	0.26	18.01	-0.61
12	Dachen	DCN	17.67	0.65	0.24	17.91	-0.24
13	Kanmen	KMN	18.20	0.56	0.17	18.42	-0.22
14	Sansha	SSA	19.21	0.71	0.21	19.91	-0.19
15	Pingtan	PTN	19.72	0.61	0.19	19.45	0.53
16	Congwu	CWU	19.98	0.52	0.17	22.18	-0.64
17	Xiamen	XMN	21.50	0.51	0.19	21.47	-2.26
18	Dongshan	DSN	20.84	0.45	0.13	21.12	-0.28
19	Yunwo	YWO	21.02	0.44	0.13	21.36	-0.34
20	Zhelang	ZLG	22.43	0.44	0.15	22.62	-0.19
21	Zhapo	ZPO	23.62	0.50	0.18	23.68	-0.06
22	Beihai	BHI	23.60	0.55	0.18	24.06	-0.46
23	Weizhou	WZU	25.79	0.43	0.17	25.66	0.13
24	Naozhou	NZU	24.46	0.49	0.16	24.44	0.02
25	Haikou	HKO	25.00	0.49	0.16	25.10	-0.10
26	Qinglan	QLN	25.80	0.44	0.18	25.86	-0.07

The quality of the data set has already been documented by Li et al., 2018; to add confidence in the quality of this data set, we compared the new data set to an independent data set of 26 local surface air temperature (SAT). Also, this data set has been homogenized - independently of the processing of the SST series. We find the SST series fully consistent with these SAT series, as well as with the gridded CRU data (not shown, see Appendix A). Thus, we conclude that our data set is superior to earlier used data on the SST variability and trends along the Chinese coast.

4. Comparison with gridded SST datasets in the Chinese coast waters

After we have found the newly homogenized SST series consistent with independent regional data, we use them as a benchmark for assessing the regional quality of the four globally gridded SST datasets (Table 1). In the following, we name the new dataset "Local homogenized SST-analysis" and refer to it as LH, while the datasets extracted from the gridded SST datasets as "localized analysis data", and use the abbreviation LA. For instance, LA-HadISST is the data set of SST found in the dataset HadISST in that grid box, which contains the locations in the LH data set.

These "localized" time series (LA) of the three gridded datasets, which extend to the full time window 1960-2015 (ERSST, HadISST, COBE SST,; referred as LA-ERSST, LA-HadISST,

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LA-COBE SST) are then compared to the local series — LH, by first comparing the standard deviations and the trends, and by calculating from trends, differences (Diff) and the root mean square errors (RMSEs) for the 26 stations (see Table 3). We do this for annual mean values. The fourth dataset, OISST data, covers a shorter time window from 1982-2015. It is used in the concluding section for clarifying some additional aspects in the section 5.

For summarizing the results, we again compute EOFs of the LH and the LAs, as well as for the differences of LH and LAs. The LH data are derived from observational stations, whereas the LA data are representing area values averaged across a grid box. Therefore, the LA data should vary less than the LH data. Possible mismatches between the local (point) LH data and the spatial averages of grid box data in the LAs may be related to small scale effects; however, the usage of EOFs is expected to reduce these truly local specifics, as the first EOFs describe joint co-variations among the 26 elements in both LA and LH data sets.

4.1. Comparing with HadISST

The 56-year mean values of local SST in the analysis LA-HadISST are in all cases higher than at the local stations (Table 3). Some differences are of the order of 2 ℃ and even 3 ℃, in particular along the East China Sea extending from SPU to ZLG (stations No. 11-20; see Fig.1). To some extent, this difference may reflect differences between averages of a larger coastal ocean area and *in situ* observations, but not entirely.

The variations in LA are similar to LH, but there are some differences: as expected, the standard deviations are in most cases (17) larger for LH, and only in few cases (9) smaller. The correlations are all large enough to reject the null hypothesis of the absence of a link (if we assume serially independence the 90%-critical value is 0.22) except for the northernmost station YWO. Part of the difference to the ideal value of 1 may be due to the different spatial scale, but values as low as 0.41 allude to more systematic differences. The trends are positive for all sites (Table 3) – only the northernmost station ZMW signals a weak downward trend in the LA-HadISST data set. In about 50% of the case, the coastal sea warms faster according to LH than according to LA-HadISST, and for 50% it is the opposite. For the two northernmost sites, ZMW and QHD station, the warming according to LA is very weak, whereas along the stretch from PTM to YWO the warming according to LA-HadISST is considerably stronger than in LH.

The time series for the two northern sites in the Bohai Sea are shown in Fig. 2. The sequence of maxima and minima share some similarity, but the trends differ markedly. The LH curves

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(red lines) exhibit both a steady increase, whereas the LA-HadISST curves (black lines) tend to decline in the first 10-20 years, and to vary at a mostly constant level (Fig.2a and 2b). In this case, the "story told" by LH is considerably different than that of LA-HadISST. The time series of the SST averaged across the stations from PTN to YWO along the East China Sea coast, where LA-HadISST indicate a stronger warming than in the LH, is shown in Fig. 2c. The local data indicate markedly lower temperatures, which may reflect by local effects, but also a weaker trend (0.18 ℃ per decade) than in the LA-HadISST (0.35 ℃ per decade).

Table 3. Statistics of the time series of the localized SST-analysis (LA-HadISST) data series at the 26 station, as well as the differences (Diff) between statistics of the LH series given in Table 1. The correlation coefficients between LH and LA-HadISST are also calculated (the 90% confidence level is 0.22, without considering serial correlation). Red numbers indicate that the correlation coefficients do not conflict with the null hypothesis of no correlation.

Station No.	Station	Mean LA-HadISST	Diff	Std deviation LA-HadISST	Diff	Trend (℃/10yrs)	Diff	Corr
1	ZMW	12.80	-1.32	0.43	-0.06	-0.02	0.25	**0.20**
2	QHD	12.93	-0.72	0.37	0.21	0.02	0.24	0.31
3	XCS	13.45	-1.76	0.46	0.38	0.13	0.16	0.73
4	LHT	13.86	-2.30	0.51	0.07	0.15	0.07	0.67
5	LKO	13.71	-0.24	0.54	0.28	0.11	0.11	0.66
6	YTI	13.92	-1.12	0.57	0.01	0.14	0.03	0.69
7	SDO	14.87	-2.58	0.58	0.01	0.19	-0.05	0.70
8	QLY	14.51	0.01	0.54	0.10	0.14	0.03	0.77
9	XMD	14.51	-0.60	0.54	0.08	0.14	0.08	0.66
10	LYG	16.05	-1.07	0.47	0.10	0.21	0.00	0.71
11	SPU	19.70	-2.00	0.57	0.08	0.12	0.14	0.63
12	DCN	20.66	-2.65	0.59	0.05	0.27	-0.03	0.67
13	KMN	20.66	-2.12	0.59	-0.03	0.27	-0.10	0.64
14	SSA	22.47	-2.30	0.70	0.01	0.35	-0.14	0.73
15	PTN	23.43	-3.00	0.75	-0.14	0.34	-0.15	0.65

16	CWU	23.43	-1.45	0.77	-0.25	0.40	-0.23	0.75
17	XMN	22.03	-2.41	0.77	-0.26	0.40	-0.21	0.78
18	DSN	24.46	-3.26	0.59	-0.14	0.30	-0.17	0.59
19	YWO	24.46	-3.08	0.59	-0.15	0.30	-0.17	0.66
20	ZLG	25.44	-2.82	0.46	-0.02	0.20	-0.05	0.83
21	ZPO	25.66	-1.78	0.51	-0.01	0.07	0.11	0.56
22	BHI	25.11	-1.47	0.31	0.24	0.07	0.11	0.53
23	WZU	25.11	0.71	0.31	0.13	0.07	0.10	0.41
24	NZU	25.65	-1.02	0.40	0.09	0.19	-0.03	0.55
25	HKO	25.65	-0.47	0.40	0.09	0.19	-0.03	0.57
26	QLN	25.93	0.09	0.43	0.00	0.22	-0.04	0.64

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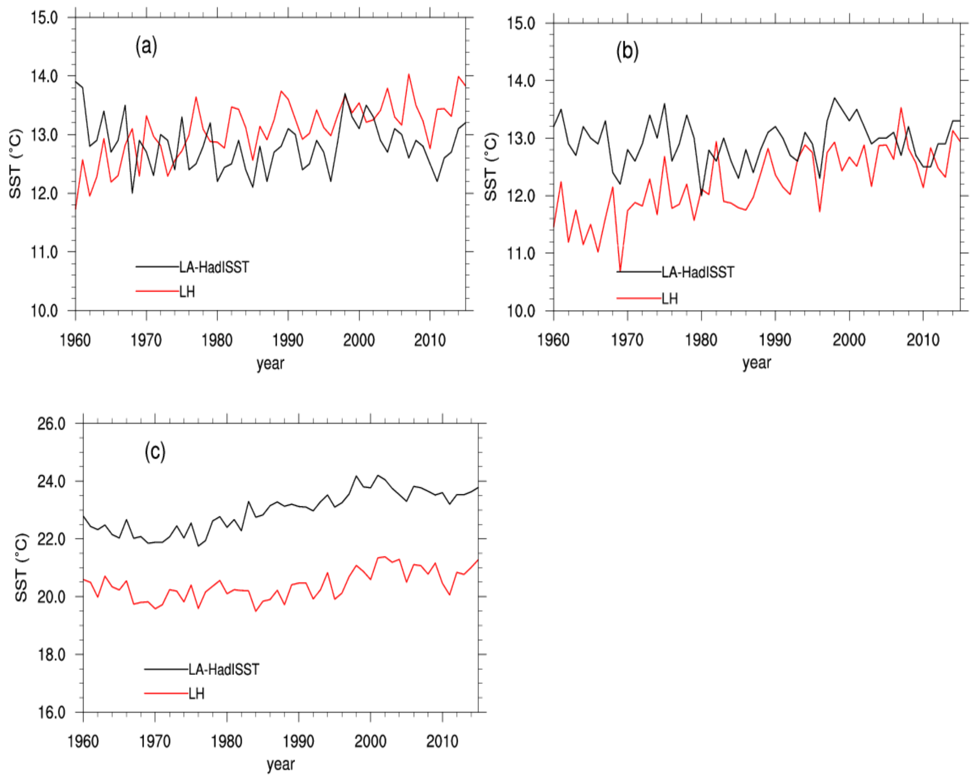


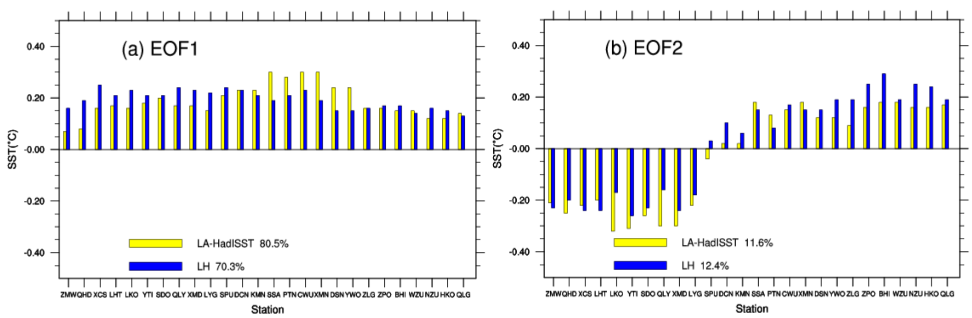
Figure 2. The annual mean SST series of LA-HadISST (black line) and LH (red line) from ZMW station **(a)** and QHD station **(b)**; The averaged annual mean SST series of LA-HadISST (black line) and LH (red line) from PTN station to YWO station **(c)**.

The first two EOFs of the LH and the LA data set have similar patterns, namely a uniform sign along the entire coast in EOF1, with similar intensities, and a north-south dipole (Bohai Sea and Yellow Sea vs. East and south China Sea), with a sign change at SPU for the second (Fig.3a and 3b). The two patterns of LH explain less, namely 82.9% of the total variance, than the LA-HadISST EOFs, which go with 92.9%. This may be related to the larger spatial variability in local data compared to gridded data. In EOF1, again the two stations QHD and ZMW in the Bohai Sea contribute less in LA-HadISST, whereas the stations PTN to YWO contribute more to the overall warming than in LA-HadISST than in LH.

The time coefficients (PCs) are broadly similar, even if the correlations are not very strong: only 0.84 and 0.42 (Fig.3c and 3d). A general warming is associated with EOF1 and mostly stationary inter-annual variability with EOF2. Again, the sequence of maxima and minima is qualitatively similar, but PC2 of LA-HadISST exhibits a break point at about 1980 – interestingly the time when satellites became routinely available of the global analyses. Before 1980, PC2 of LH and LA-HadISST differed by about 0.2 ℃ (Fig. 3d; this corresponds to a mean difference of 0.04 ℃ at the southern stations during that time, and a mean difference 0.04 ℃ at the northern stations (Fig. 3b)).

To further study the differences in trends, EOFs were calculated from the difference time series, that is, LH anomalies minus LA-HadISST anomalies at the 26 sites (Fig. 4). The first two EOFs stand for 31.2% and 27.6% of the variance. These numbers are not very different, and it their closeness may be indicative that the EOFs are degenerate (von Storch & Zwiers 1999). These EOFs describe covariations of the differences along long stretches of the coast; in case of EOF1, this is the case for all stations south of SPU, i.e., in the East and South China Sea (Fig.4a). In EOF2 it is all stations south of KMN, mostly in the Yellow Sea and Bohai Sea (Fig. 4b). PC1 seems to describe a change point at about 1980, whereas PC2 describes a slight upward trend: The difference time series tend to be larger in earlier years and are almost nil in the end of the considered time interval. That is, in recent years, there are little differences between LA-HadISST and LH, which is not surprising giving the better observational and reporting practice.

That in early years inhomogeneities impacted the quality of SST analyses is also not surprising, but it is valuable to learn when these inhomogeneities took place, and which time periods in the analyses should be taken with some reservation. Of course, this assertion depends on the assumption that the homogenization of the local data did remove all break points and other inhomogeneities.



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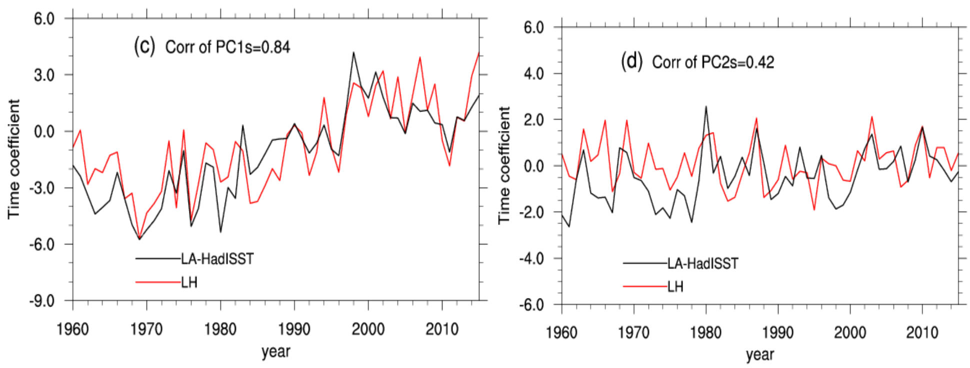

Figure 3. Comparison of the EOF1 and EOF2 derived from the LH data set of local SST at 26 sites (blue bars; red lines), and derived from the localized analysis data LA-HadISST (yellow bars; black lines). Top: EOF spatial patterns, bottom: principal components (time coefficients).

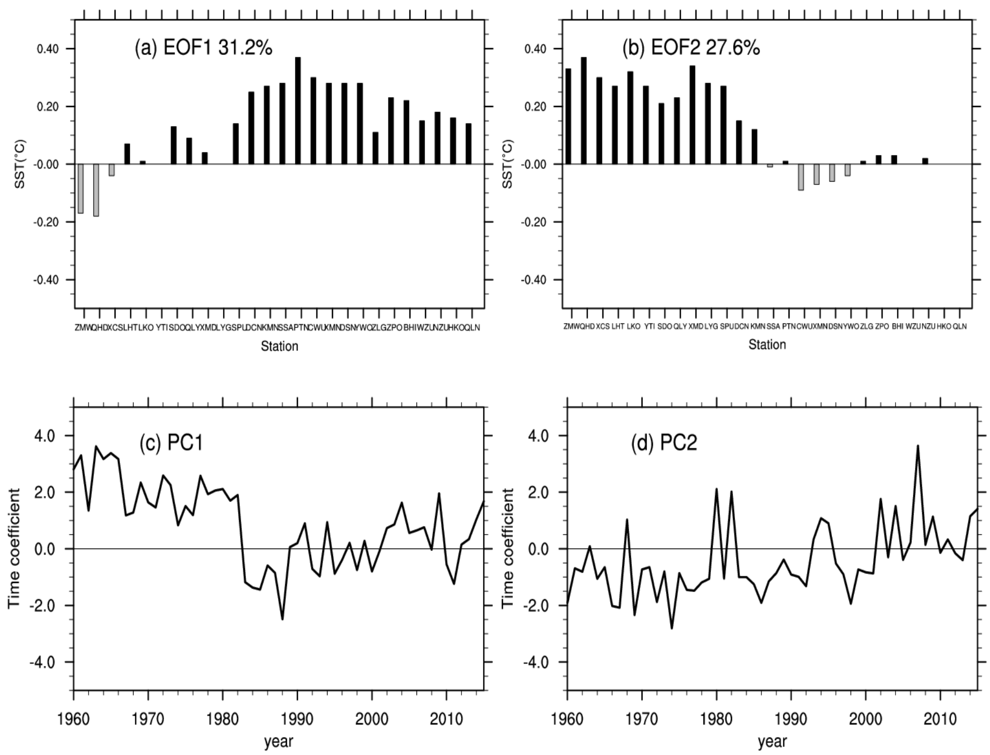

Figure 4. First two EOFs of the difference time series LH-LA-HadISST. Top: EOF spatial patterns, bottom: principal components (time coefficients) .

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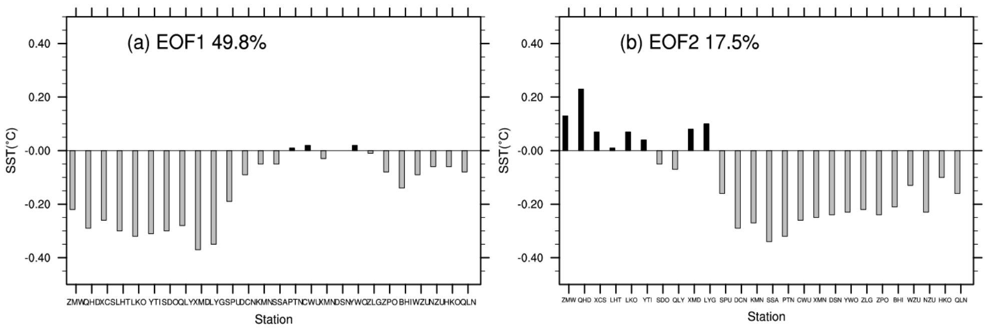
4.2 Comparing with COBE SST

In this subsection, we consider the localized SST derived from the LA-COBE SST data set during 1960-2015. Again, the LA-COBE SST is in almost all sites higher than the local data, namely at 21 out of 26 sites. The differences are up to 3 ℃, and again mostly along the East China Sea coast from SPU to ZLG (not shown, see Table SOM-1 in the Supplementary Online Material (SOM)). The local correlations are relatively high, namely between 0.55 and 0.85. The EOFs derived from the LA-COBE SST, with the same grid resolution of 1^{o}, and the same time window 1960-2015, as LA-HadISST exhibits broadly the same pattern in space and time as the EOFs of the LH data. Also, the explained variances are close (not shown, see Figure SOM-2). When comparing details, the northern stations contribute more to the overall warming represented by EOF1, whereas the stations along the South and East China Sea contribute less. Again, the two northernmost stations ZMW and QHD exhibit some systematic differences, both in EOF1 and EOF2. The PCs share correlations of 0.80 for EOF1 and 0.50 for EOF2. COBE SST does not capture the recovery of the dip in warming since about 2000, as LH and HadISST did, while EOF2 reveals some warming in the final years. During the 1960s some differences prevail.

Fig.5 shows the EOFs of the difference time series between LH anomalies and LA-COBE SST anomalies. The first EOF dominates, with 49.8%, whereas the second one represents a share of 17.5%. The first EOF points to several inhomogeneities, with two prolonged intervals during which LH is higher than LA-COBE SST (say, 1960-1978, and 1995-2005), and a strong drop-down do negative PC-values after about 2005. PC2, on the other hand, appears as mostly stationary, except for a suspiciously negative episode in the early 1960s.



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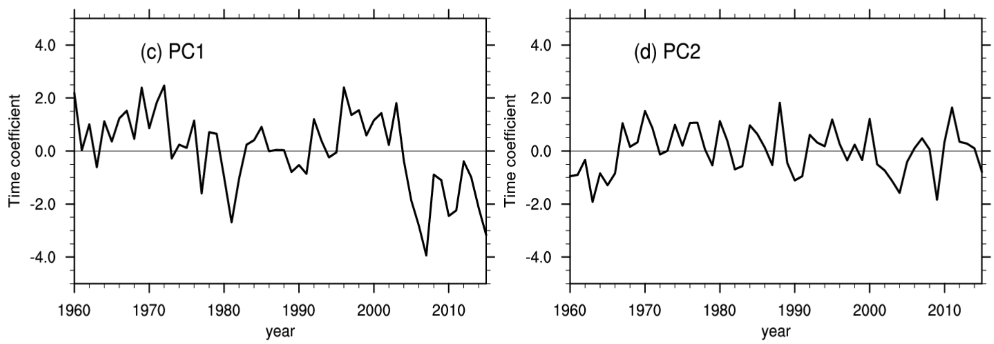

Figure 5. EOF analysis of the differences LH-LA-COBE: Top: EOF spatial patterns (EOFs), bottom: principal components (time coefficients).

4.3 Comparing with ERSST

ERSST presents SST on a coarser grid compared to the two cases before, namely 2^o by 2^o. Again, the temperatures given by ERSST, as was the case with the other two analyses, is higher than the temperatures recorded at the local sites along the coast (not shown; see Table SOM-2). The differences are up to 4^o, and the largest differences are found in the East China Sea from SPU to ZLG. That the differences are in this case even larger than in the other LA cases may be related to the 2^o resolution of ERSST.

The variability according to ERSST is quite similar to that of LH, at least in terms of EOFs (not shown; see Figure SOM-3). The correlation of the PC1 is amount to 0.83, and of PC2 to 0.60. LA-HadISST got 0.84 and 0.42, LA-COBE SST got 0.80 and 0.50. The local correlations vary between 0.37 and 0.82. Again EOF1 stands for an overall warming and EOF2 to interannual variability with hardly a trend. The relative contributions of the two EOFs compare well to the LH-EOFs. In detail, the northernmost stations appear stronger in EOF1 of LA-ERSST than in that of LH, whereas the northern sites are underrepresented, and the southern over-represented in EOF2.

The EOFs of the differences between LH anomalies and LA-ERSST anomalies are shown in Fig. 6. They differ strongly from those found for LA-COBE SST and LA-HadISST. The first EOF differences resemble the first EOFs of LH and LA-ERSST (not shown; see Fig. SOM-3) – the long-term trend in LA-ERSST is smaller than in the local data – everywhere. The second EOF is again a dipole pattern, with the Yellow Sea and Bohai Sea on the one side, and the East and South China Sea on the other. PC2 is mostly stationary.

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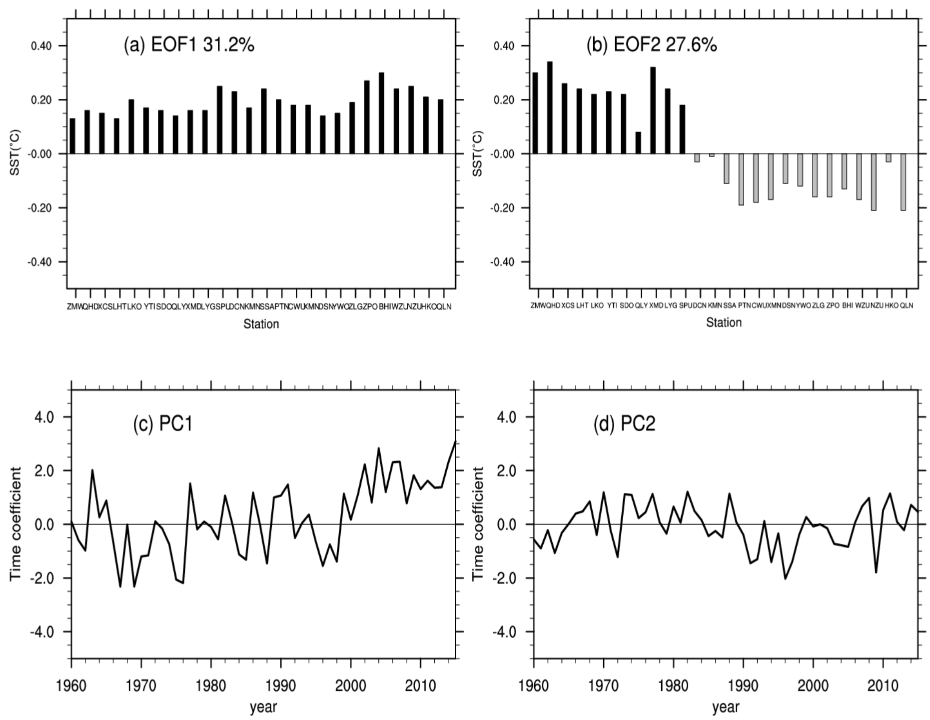

Figure 6. Spatial variability of the EOF1 (a); EOF2 (b) mode of the differences between LH anomalies and LA-ERSST anomalies (LH anomalies minus LA-ERSST anomalies). And the time coefficient series of PC1(c) and PC2 (d) from 1960 to 2015.

5 Discussion and conclusion

We have mainly examined three global analysis data sets of sea surface temperature (SST) in the Chinese coastal waters. For doing so, we have compared a number of statistical properties for 26 coastal hydrological locations as given by the analyses and by a newly digitized and homogenized data set (Li et al., 2018). For demonstrating the utility of the local data set, named LH in the following, we have compared the local SST series with independent local homogenized surface air temperature (SAT) data from nearby meteorological stations. The variations of the two series are fully consistent. Another argument alluding to the quality of the LA data set is that the differences between LH and the three LAs (localized data from the different global analyses) considered are not uniform (except for the time mean); instead the LAs deviate in different ways from LH. If this would not be the case, one could be tempted to argue that the differences are manifestations of inefficiencies of the LH data set. This is not the case.

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Our main results are:

- The mean SST in LH at many sites is considerably lower than that in the LA-data. We suggest that this is related to the coastal position of LH, and the averaging in the LA data. Consistent with this hypothesis is that the differences are largest in the case of the coarsest analysis (ERSST), but weakest in the OISST-data set with a resolution of a quarter of a resolution degree (Fig. 7) (Note that the difference LH minus LA-OISST is restricted to the warmer episode 1982-2015). However, systematic differences would not be expected to influence strongly the overall variability and trends.
- The first EOF in all data sets stands for a general warming, and the second for interannual variability. This is not only so in the local LH-data but also in all globally gridded-based LA-datasets.
- In the years following the introduction of satellites in monitoring SST, since abut 1980, the different global analyses converge, and the differences to the local data set become smaller. In support of this, the comparison with the high resolution analysis OISST for the post-satellite time 1982-2014 reveals few differences (not shown, see Fig. SOM-4).
- In the years before 1980, some noteworthy differences are found. The differences between the LH-data anomalies and the LA-data anomalies are non-uniform across the different LA data sets. For instance, for ERSST the long-term trends differ, in case of COBE SST several jumps emerge, and in case of HadISST, a jump is found at the time of the advent of the routine satellite data, but also a trend in PC2 of the differences.

Thus, our overall conclusion is that the global gridded SST datasets correctly describe the main features of variabilities and trends in regional waters, but that significant improvements in the regional analyses may be gained when quality controlled homogenized data are incorporated. In particular for the time prior to the usage of remote sensing by satellites, and in regions where observational efforts have been limited, such efforts are valuable contributions to climate variability and change studies. Our example should also be an encouragement for national climate services to revisit regional data, and to invest into the elimination of inconsistencies caused by inhomogeneities.

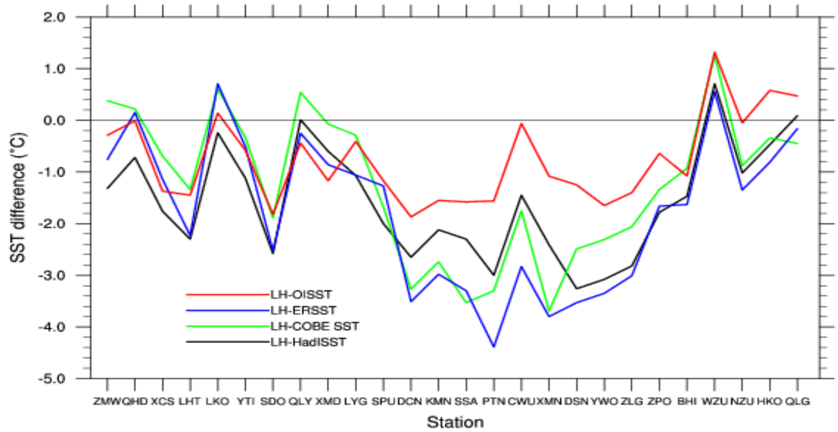

Figure 7. The mean SST differences at the 26 locations between LH and LA-OISST (1982-2015; red line), LH and LA-ERSST (1960-2015; blue line), LH and LA-COBE SST (1960-2015; green line) and LH and LA-HadISST (1960-2015; black line)

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Appendix A: Consistency of homogenized SST data set with homogenized SAT data set

We examine if the SST data is consistent with other local homogenized data, specifically with time series of SAT at various locations along the Chinese coast. This data set contains data from many sites. For each of the SST measuring sites, there is at least one SAT stations within 100 km distance. We select one such SAT station with higher correlation relationship with SST time series, and form 26 pairs of located SST/SAT data. However, we do not compare the SST and SAT data directly, but we derive for both times series empirical orthogonal functions (EOFs), and compare the patterns and the coefficient time series (PCs) of the two EOF sets (Fig. A1). It turns out that the patterns are similar. When compared to series drawn from the gridded CRU TS 3.24.01, we find a strong similarity (not shown, see Fig. SOM-1).

The first EOFs of SST and SAT *in site* describe an overall warming, with a slight tendency of stronger warming in terms of both SST and SAT in the northerly Bohai and Yellow Sea (Fig. A1a). This pattern is dominant, representing 70.3% and 76.7% of the total interannual variance. The warming is mostly continuous from about 1970 until 2010 (Fig. A1c). The similarity of the principal components – expressed by 0.97 in terms of the correlation coefficient – is striking (Fig. A1c). The second EOF (Fig. A1b) explains considerably less variance – namely about 11.6%. They describe a North-South contrast, and stationary PCs, varying around 0 without prolonged positive or negative excursions (Fig. A1d). Also the PCs of the second PCs of SST and SAT show a remarkably parallel development – with a high correlation of 0.86 (Figs.A1d). The PCs of SAT-CRU also show high correlations of 0.94 and 0.83 with the SST *in site* (not shown, see Fig. SOM-1).

We conclude that the two data sets are consistent; the first EOFs describe the warming of the recent decades of years; the second EOFs describe interannual variability, and may be influenced by ENSO and other patterns of natural variability. We furthermore conclude that the new description of SST variability and trends at the 26 sites along the Chinese coast presents a reliable account of the past since 1960 – and thus may serve as a benchmark for assessing global analyses of SST datasets.

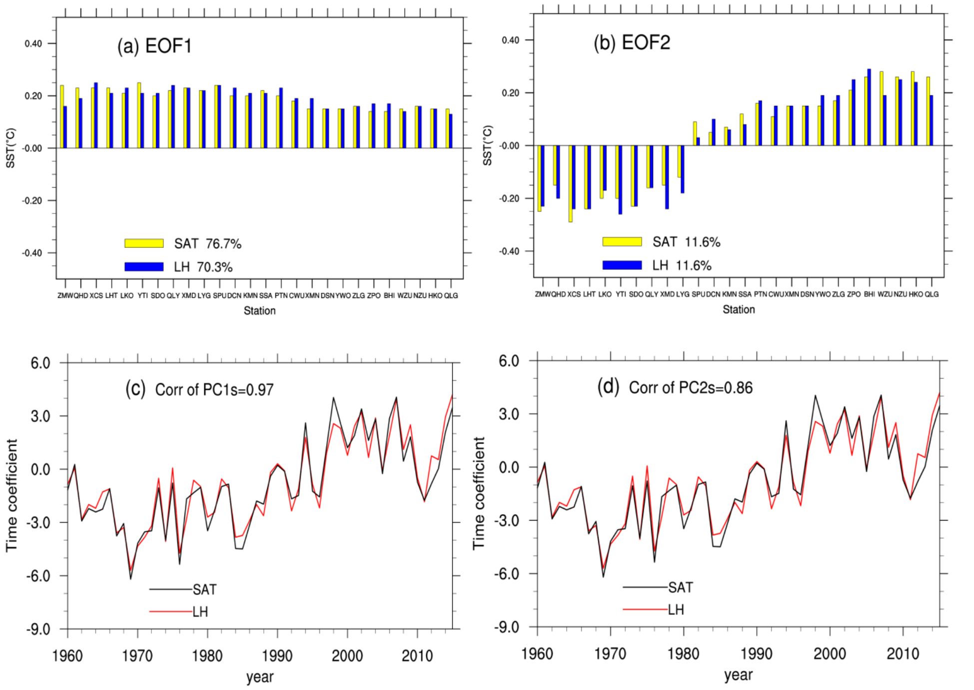
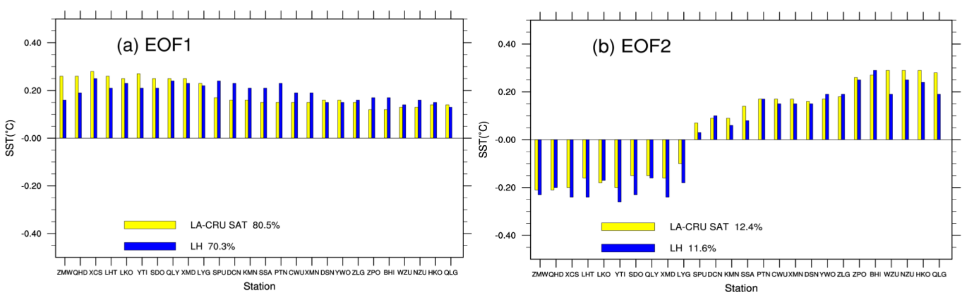


Fig. A1. Comparison of the EOF1 and EOF2 derived from the LH data set of local SST at 26 sites (blue bars; red lines), and derived from the SAT at the same sites (yellow bars; black lines). Top: EOF spatial patterns, bottom: principal components (time coefficients).

Appendix B: Supplementary Online Material (SOM)



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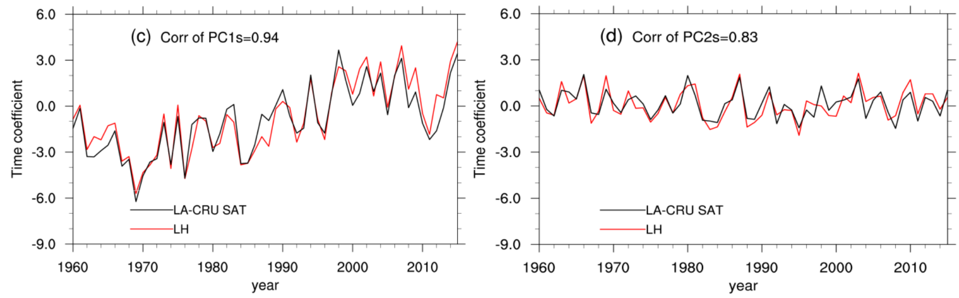

Fig. SOM-1. Comparison of the EOF1 and EOF2 derived from the LH data set of local SST at 26 sites (blue bars; red lines), and derived from the CRU SAT at the same sites (yellow bars; black lines). Top: EOF spatial patterns, bottom: principal components (time coefficients).

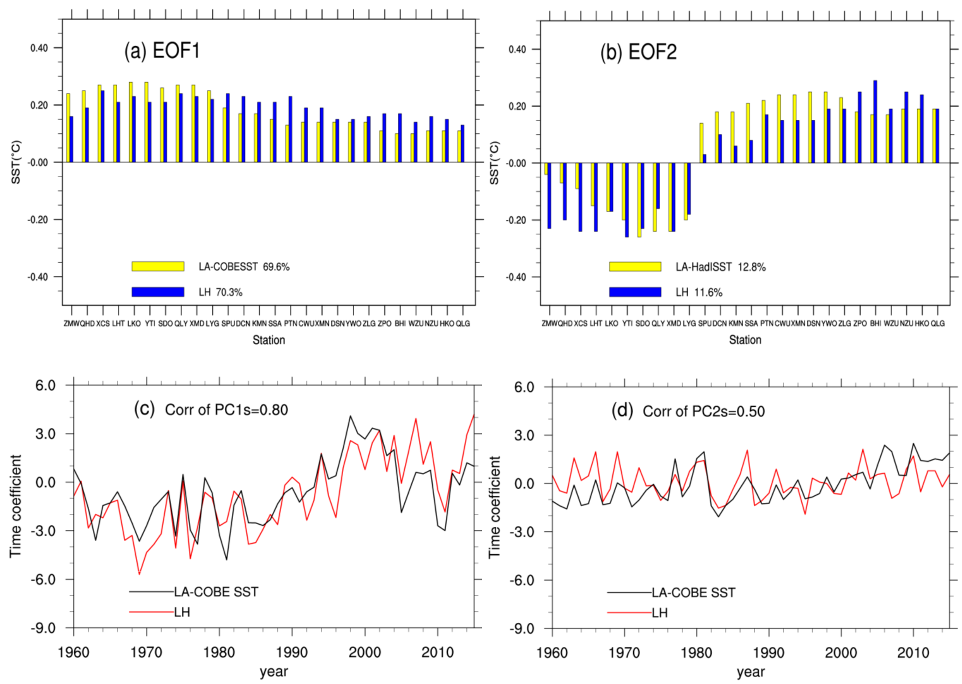

Fig. SOM-2. Comparison of the EOF1 and EOF2 derived from the LH data set of local SST at 26 sites (blue bars; red lines), and derived from the localized analysis data LA-COBE SST (yellow bars; black lines). Top: EOF spatial patterns, bottom: principal components (time coefficients).

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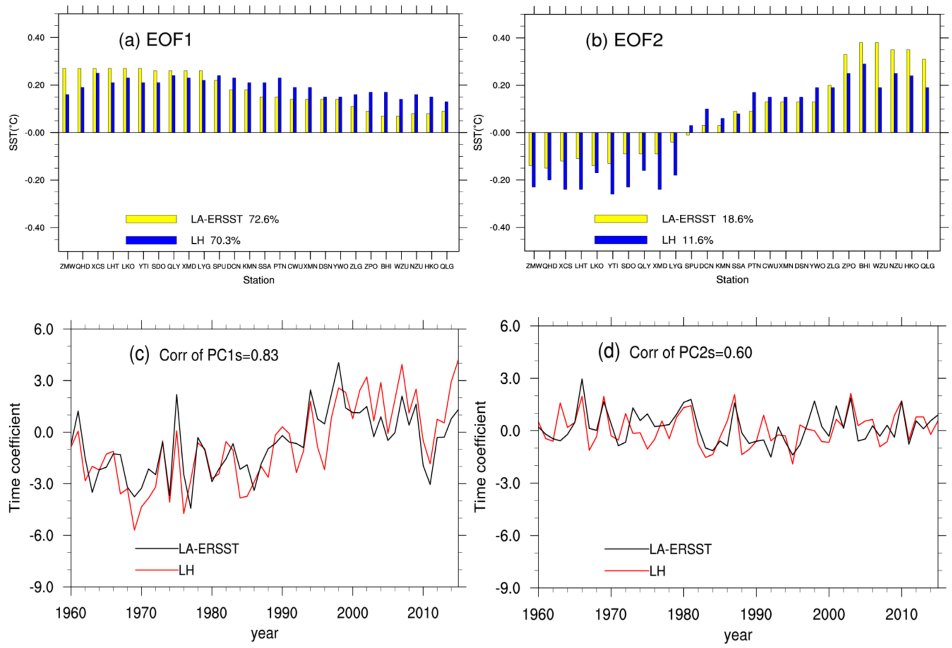

Fig. SOM-3. Comparison of the EOF1 and EOF2 derived from the LH data set of local SST at 26 sites (blue bars; red lines), and derived from the localized analysis data LA-ERSST (yellow bars; black lines). Top: EOF spatial patterns, bottom: principal components (time coefficients).

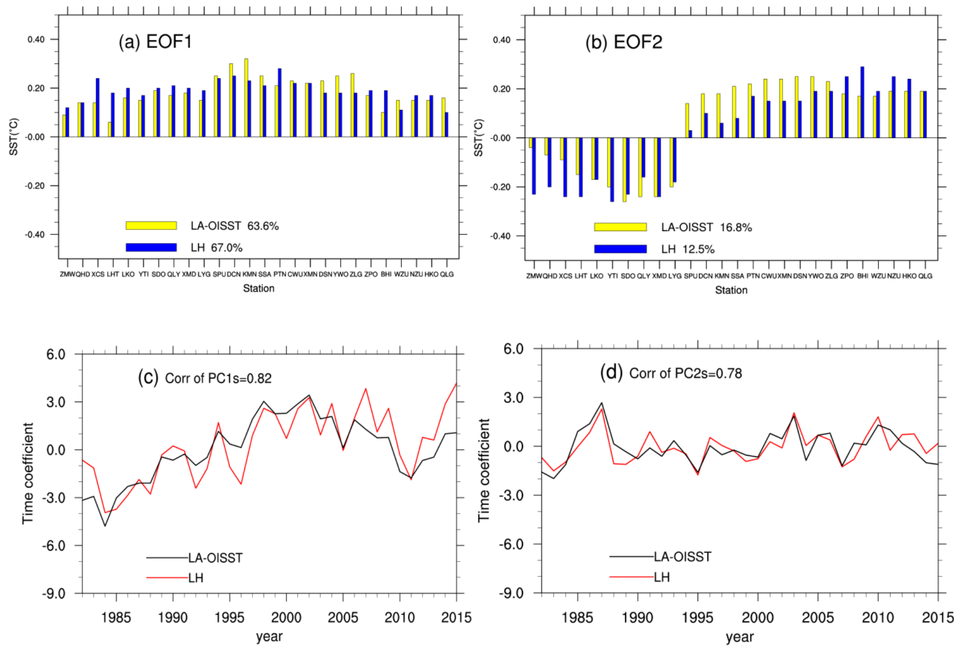

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Fig. SOM-4. Comparison of the EOF1 and EOF2 derived from the LH data set of local SST at 26 sites (blue bars; red lines), and derived from the localized analysis data LA-OISST (yellow bars; black lines). Top: EOF spatial patterns, bottom: principal components (time coefficients).

Table SOM-1. Statistics of the time series of the localized SST-analysis (LA-COBE SST) data series at the 26 station, as well as the differences (Diff) between the pairs of time series. The correlation coefficients between LH and LA-COBE SST are also calculated (the 90% confidence level is 0.22, without considering serial correlation). Red numbers indicate that the correlation coefficients do not exceed the 90% confidence level.

No	station	Mean LA-COBE SST	Diff	Std-dev LA-COBE SST	Diff	Trend (℃/10yrs)	Diff	Corr
1	ZMW	11.13	0.38	0.52	0.01	0.17	0.00	0.60
2	QHD	11.99	0.22	0.54	0.04	0.16	0.10	0.56
3	XCS	12.23	-0.69	0.56	0.14	0.14	0.15	0.74
4	LHT	12.70	-1.34	0.59	0.00	0.10	0.11	0.59
5	LKO	12.75	0.61	0.60	-0.01	0.10	0.12	0.64
6	YTI	12.98	-0.33	0.61	-0.03	0.07	0.10	0.66
7	SDO	13.98	-1.89	0.61	-0.02	0.01	0.13	0.68
8	QLY	13.83	0.54	0.62	0.03	0.04	0.13	0.72
9	XMD	13.83	-0.07	0.62	0.01	0.03	0.19	0.55
10	LYG	15.14	-0.29	0.57	0.00	0.03	0.18	0.55
11	SPU	19.09	-1.68	0.45	0.20	0.18	0.08	0.77
12	DCN	20.94	-3.27	0.43	0.22	0.19	0.05	0.81
13	KMN	20.94	-2.74	0.43	0.13	0.19	-0.02	0.78
14	SSA	23.25	-3.53	0.38	0.22	0.20	0.01	0.82
15	PTN	23.29	-3.30	0.41	0.11	0.20	-0.01	0.79
16	CWU	23.29	-1.75	0.41	0.10	0.20	-0.03	0.85
17	XMN	22.90	-3.69	0.40	0.14	0.19	0.00	0.78
18	DSN	23.33	-2.49	0.41	0.04	0.21	-0.08	0.68
19	YWO	23.33	-2.31	0.41	0.02	0.21	-0.08	0.77
20	ZLG	24.49	-2.06	0.40	0.04	0.18	-0.03	0.81
21	ZPO	24.95	-1.34	0.33	0.17	0.11	0.07	0.80
22	BHI	24.53	-0.93	0.34	0.21	0.10	0.08	0.78
23	WZU	24.53	1.26	0.34	0.09	0.10	0.07	0.73
24	NZU	25.34	-0.88	0.35	0.14	0.12	0.04	0.77
25	HKO	25.34	-0.34	0.35	0.13	0.12	0.04	0.85
26	QLN	26.25	-0.45	0.36	0.08	0.13	0.05	0.68

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Table SOM-2 Statistics of the time series of the localized SST-analysis (LA-ERSST) data series at the 26 station, as well as the differences (Diff) between the pairs of time series. The correlation coefficients between LH and LA-ERISST are also calculated (the 90% confidence level is 0.22, without considering serial correlation). Red numbers indicate that the correlation coefficients do not exceed the 90% confidence level.

No	Station	Mean LA-ERSST	Diff	Std-dev LA-ERSST	Diff	Trend (℃/10yrs)	Diff	Corr
1	ZMW	12.26	-0.76	0.53	0.00	0.16	0.01	0.69
2	QHD	12.06	0.15	0.55	0.03	0.17	0.09	0.70
3	XCS	12.68	-1.14	0.54	0.17	0.17	0.12	0.82
4	LHT	13.59	-2.23	0.52	0.07	0.16	0.05	0.78
5	LKO	12.65	0.71	0.54	0.05	0.16	0.06	0.77
6	YTI	13.16	-0.51	0.52	0.06	0.16	0.01	0.79
7	SDO	14.62	-2.53	0.50	0.09	0.14	0.00	0.76
8	QLY	14.62	-0.25	0.50	0.14	0.14	0.03	0.85
9	XMD	14.62	-0.86	0.50	0.12	0.14	0.08	0.78
10	LYG	15.92	-1.06	0.50	0.07	0.12	0.09	0.81
11	SPU	18.68	-1.27	0.46	0.19	0.10	0.16	0.65
12	DCN	21.18	-3.51	0.37	0.28	0.12	0.12	0.70
13	KMN	21.18	-2.98	0.37	0.19	0.12	0.05	0.71
14	SSA	24.37	-4.39	0.32	0.20	0.12	0.09	0.69
15	PTN	24.37	-2.83	0.32	0.19	0.11	0.08	0.75
16	CWU	23.02	-3.80	0.33	0.22	0.11	0.06	0.77
17	XMN	23.02	-3.30	0.33	0.28	0.12	0.07	0.71
18	DSN	24.37	-3.53	0.32	0.13	0.11	0.02	0.63
19	YWO	24.37	-3.35	0.32	0.12	0.11	0.02	0.65
20	ZLG	25.44	-3.01	0.31	0.13	0.09	0.06	0.67
21	ZPO	25.28	-1.66	0.35	0.14	0.04	0.14	0.56
22	BHI	25.23	-1.63	0.41	0.15	0.02	0.18	0.49
23	WZU	25.23	0.56	0.41	0.03	0.03	0.17	0.37
24	NZU	25.81	-1.35	0.37	0.12	0.01	0.16	0.54
25	HKO	25.81	-0.81	0.37	0.11	0.01	0.16	0.66
26	QLN	25.96	-0.16	0.34	0.10	0.05	0.13	0.47