Ocean Sci. J. (2015) 50(1):109-117
http://dx.doi.org/10.1007/s12601-015-0009-1

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Available online at http://link.springer.com
SpringerLink

Ocean Science Journal
pISSN 1738-5261
eISSN 2005-7172

Long-term Comparison of Satellite and in-situ Sea Surface Temperatures around the Korean Peninsula

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Received 9 October 2014; Revised 5 January 2015; Accepted 3 February 2015

Abstract – Satellite remotely sensed sea surface temperature (SST) was compared with in-situ SST in the seas around the Korean Peninsula from 1984 to 2013. A matchup dataset between satellite and in-situ SSTs was used. The root mean square error (RMSE) between satellite and in-situ SSTs was approximately 1°C in the offshore area and 2~3°C in the coastal area. The satellite SST exhibits a cold bias of 1°C or less in the offshore area and a warm bias of 1~3°C in the coastal area. The satellite SSTs generally agree with the in-situ data in the East/Japan Sea (EJS) better than in the South Sea and the Yellow Sea (YS). The RMSE between the two SSTs in the South Sea (SS) is 1~2°C. In-situ and satellite SST analyses respectively indicate a warming trend of 0.024°C/year and 0.011°C/year for the study period in the seas around the Korean Peninsula. The difference in the long-term trends from the two data sources is mainly due to the difference in the YS. The satellite SST showed a warm bias of 0.5~1.0°C in the early 1980's and a cold bias of 0.5°C in the early 2010's, which should be carefully considered in studying long-term trends with satellite SST data.

Key words – satellite SST, in-situ SST, RMSE, long-term trend

1. Introduction

Temperature changes of the ocean affect significantly the flow of sea water and also marine ecosystems, fisheries, climatology and meteorology. In relation to recent climate changes, there has been growing interest in sea surface temperature (SST) changes due to global warming (Seo et al. 2014). SST is also a key parameter in air-sea interaction. Compared with highly sparse in-situ SST data, satellite observations can provide spatio-temporally high resolution information. Daily satellite SST data have been widely used in oceanography for various purposes including studies on climate changes and data assimilation (Seo et al. 2010, 2014). The global average of the root mean square error (RMSE) between in-situ and satellite SSTs is known to be about 0.6~0.7°C (Strong and McClain 1984; McClain 1989).

In several studies, the accuracy of satellite SSTs has been evaluated. Particularly, National Oceanic and Atmospheric Administration (NOAA) satellite SSTs were compared with in-situ SSTs in the Northwestern Pacific (Lee et al. 2005; Sakaida and Kawamura 1992; Park et al. 2008a) and in the seas around the Korean Peninsula (Park et al. 1994, 1999, 2011). According to Park et al. (2008a), the RMSE between satellite and in-situ SSTs is about 0.89°C in Northeast Asian seas and also less than 1°C in the seas around the Korean Peninsula (Park et al. 1994, 2011).

The causes of difference between in-situ and satellite SSTs are diverse in time and space (Park et al. 2008a). Drifting buoy observations are generally closer to satellite data and allow more adequate comparison of the two data sources (Park et al. 2008b), compared with the ship based measurements. However, temperatures are not measured at a fixed point with drifting buoys, leading to limitation in understanding the statistics of the temperature difference between satellite and in-situ temperatures especially for long term analyses.

The SST in the seas around the Korean peninsula shows various small scale phenomena due to complex topography, large circulation variability, and strong tidal currents. The coastal cold water appears frequently due to tidal mixing in the Yellow Sea (YS) (Cho et al. 2000; Sun and Cho, 2010)

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and advection of the North Korean Cold Current in the East/Japan Sea (EJS) (Cho and Kim 2000). The SST in the South Sea (SS) of the Korean Peninsula is directly affected by the Tsushima Warm Current (Kim et al. 2005).

The objective of this study is to evaluate the accuracy of satellite SSTs by comparison with in-situ SSTs routinely observed for long period, which will help us to understand limitation of satellite data in studying long-term SST changes and to assess the local error of satellite observations in marginal seas like the study area.

2. Data and Method

Since early 1960s, the National Fisheries Research and Development Institute (NFRDI) has regularly observed temperature and salinity of the seas around the Korean Peninsula bi-monthly in February, April, June, August, October, and December. The observation stations of NFRDI are plotted in Figure 1. In-situ SST was observed by SBE 911 plus CTD whose accuracy is ± 0.001°C in temperature.

The study period is between 1984 and 2013. The satellite SST dataset is obtained from the AVHRR (Advanced Very High Resolution Radiometer) of NOAA for the period (http://www.ncdc.noaa.gov/sst/) (Reynolds et al. 2007). A matchup dataset between satellite and in-situ SSTs were generated for the analysis. We selected satellite SST corresponding to in-situ temperature in location and date. The study area is 32~39°N, 123~133°E, which is divided into coastal and offshore areas to compare the accuracy of satellite SSTs in each area. Since the EJS, the SS and the YS have different topographic features and flow systems, the SST difference for each of the seas is also analyzed.

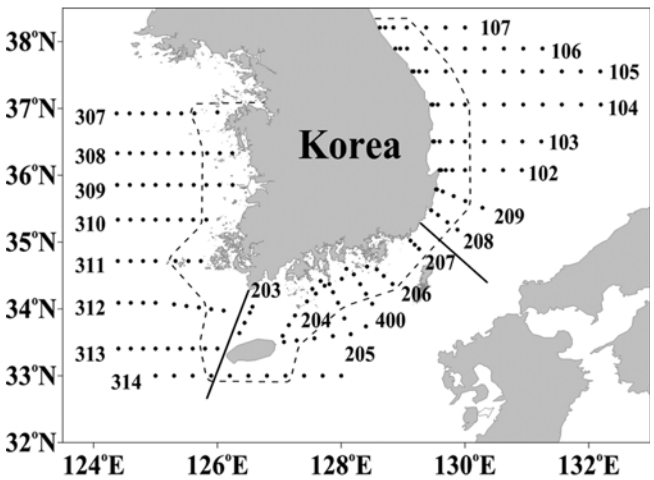

Fig. 1. In-situ observation stations of the National Fishery Research and Development Institute, Korea. Dashed line is the boundary between the coastal area and the offshore area. Solid lines represent the boundaries among the East/Japan Sea, the South Sea and the Yellow Sea

3. Results

Bi-monthly mean SST distribution

Figure 2 and Figure 3 respectively show bi-monthly in-situ and satellite SST means for 30 years from 1984 to 2013. The satellite SST is comparable with the in-situ SST in many respects. For both data sources, the SST is the highest in August and the lowest in February. Spatio-temporal changes are similar in both SSTs in general. However, a closer look at the SST structures reveals differences between the in-situ and satellite SSTs. The seasonal amplitude of the coastal SST is generally greater than that in the offshore SST. The satellite SST along the west coast of the Korean Peninsula is higher by about 2°C than the in-situ SST. The lowest in-situ SST is about 4°C in the west coast of Korea in February, whereas the lowest satellite SST 5°C. Similar difference is shown in April.

The in-situ SST in the coastal area of the YS is lower by 1~2°C than the offshore area in June, August and October due to strong tidal mixing (Sun and Cho 2010), and similarly, the coastal SST in the EJS is lower by about 1°C than the offshore water due to the southward flow of the North Korean Cold Current (NKCC) (Cho and Kim 2000). There is a significant difference between in-situ and satellite SSTs in the coastal area.

The RMSE and the satellite bias were calculated to quantify the difference. Figure 4 shows the bias of the satellite SST averaged for 30 years at each observation station in each measurement month. In general, positive biases are shown in the coastal area and negative biases in the offshore regions. For all periods, the magnitude of the coastal bias is larger compared with the offshore bias. The bias is the maximum of -3°C February in the southwest coast. The SST bias decreases in April through October, and begin to increase in December. The large bias in the coastal area suggests that the satellite SST has limitation in resolving the coastal cold water.

Figure 5 shows the horizontal distribution of the RMSE between in-situ and satellite SSTs in each month for 30 years. The RMSE in the seas around the Korean Peninsula is mostly less than 1°C (Figure 5), which agrees with the

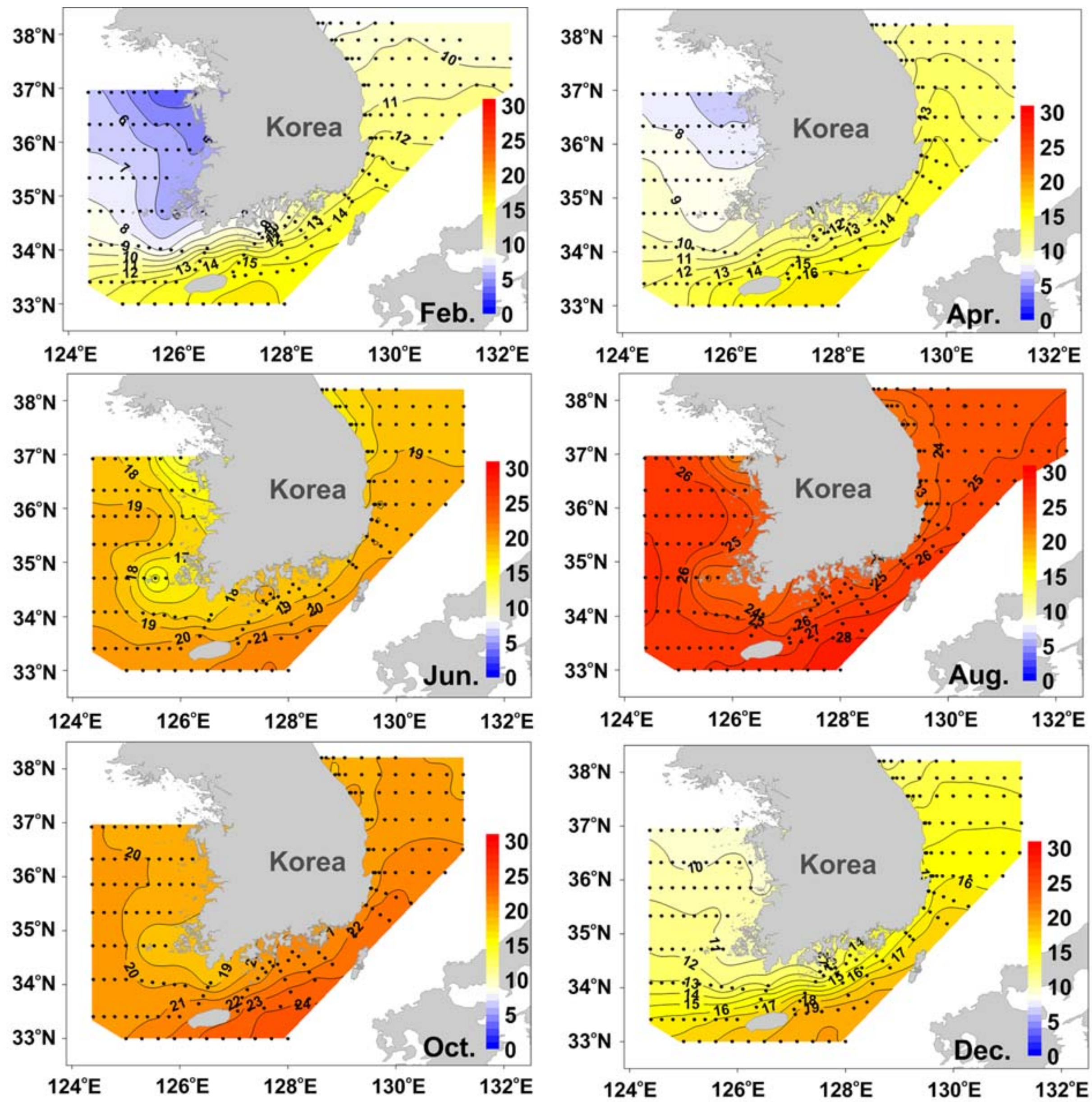

Fig. 2. Mean distribution of in-situ sea surface temperature observed by NFRDI in measurement months for 30 years from 1984 to 2013

findings in Park et al. (2011). However, the RMSE is more than 2°C in the coastal areas of the YS and the SS during the whole periods. The RMSE in the EJS is more than 2°C in August, but less than 2°C in other months. Overall, there is little difference between in-situ and satellite SSTs in all seas in April and October.

Comparison between the coastal and the offshore SSTs

In this section, the coastal and the offshore regions are statistically analyzed in more detail. The boundary of the two areas is about 100 km from the coast line (dotted line in Figure 1).

Time series of annual mean SST (top), and the RMSE and the bias (bottom) between in-situ and satellite SSTs for the study period are examined in Fig. 6 through Fig. 11. The time series of in-situ SST in the offshore (Fig. 6) and the coastal (Fig. 7) areas show that the long-term SST trend is nearly the same between the offshore area (0.029°C/year) and the coastal area (0.026°C/year). However, for satellite data, the long-term trend in the offshore (0.007°C/year) is smaller

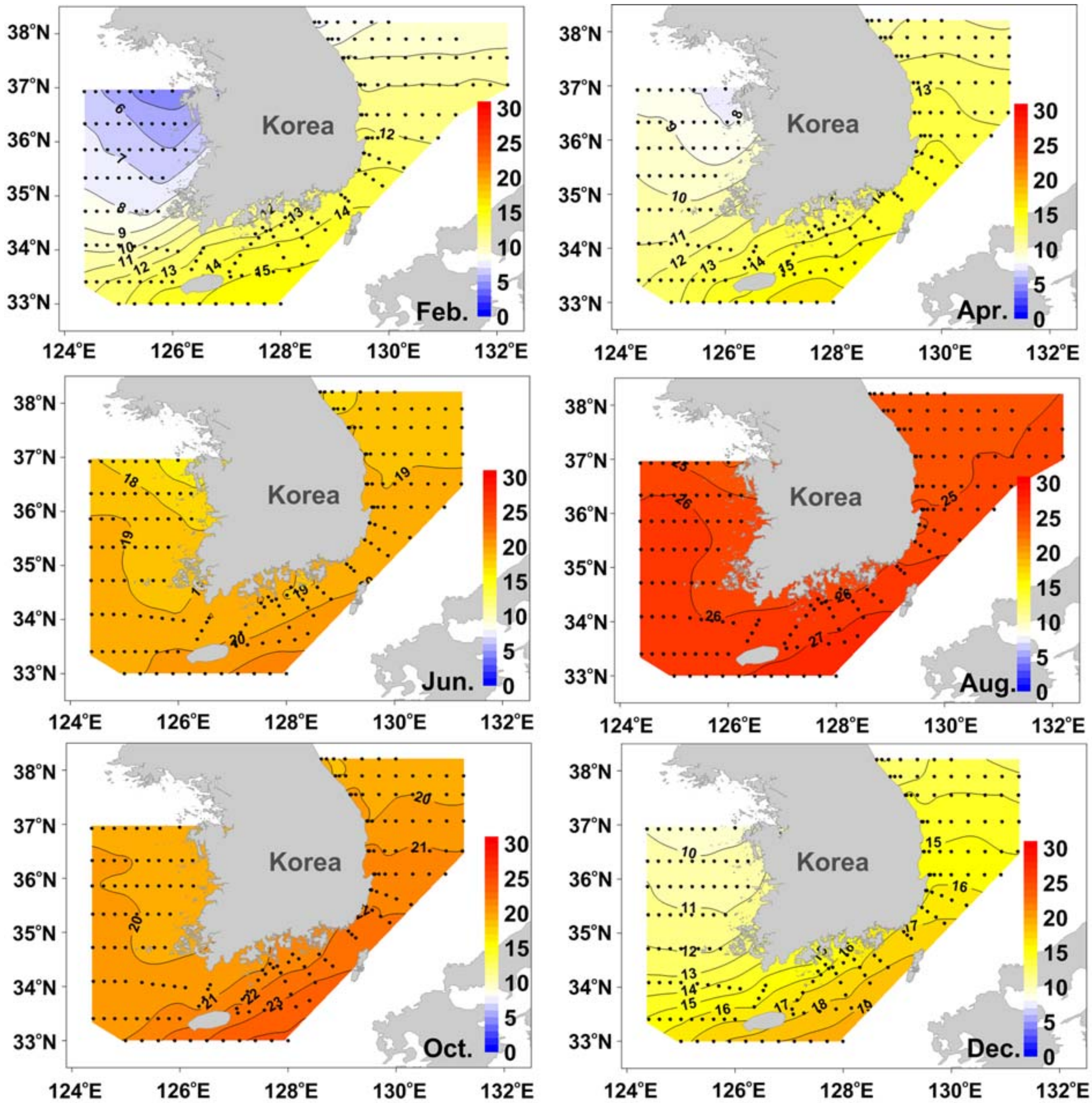

Fig. 3. Mean distribution of satellite (NOAA/AVHRR) sea surface temperature subsampled for in-situ observation periods for 30 years from 1984 to 2013

approximately three times than that in the coast (0.022°C/year). The RMSE is about 1.5°C in the coastal SS and 1.0°C in the offshore SST. The difference is maintained during the whole period. The coastal satellite SST exhibits consistently positive bias of about 0.5°C during the entire period. On the other hand, the offshore satellite SST shows a positive bias until 2000 and then a negative bias after that, leading to the long-term trend much slower than the coastal long-term trend. However, the overall offshore bias is rather small, less than 0.3°C in magnitude.

Regional comparison

The YS, the SS and the EJS have different oceanic conditions. The SS and the EJS are greatly affected by the Tsushima Warm Current, while the YS is less affected by ocean currents (Cho and Kim 2000). The YS is characterized by active vertical mixing because of its shallow depth and strong tidal currents (Sun and Cho 2010). The different conditions might result in different SST variations in each sea, which could be statistically analyzed. The boundaries of the seas are shown in Figure 1.

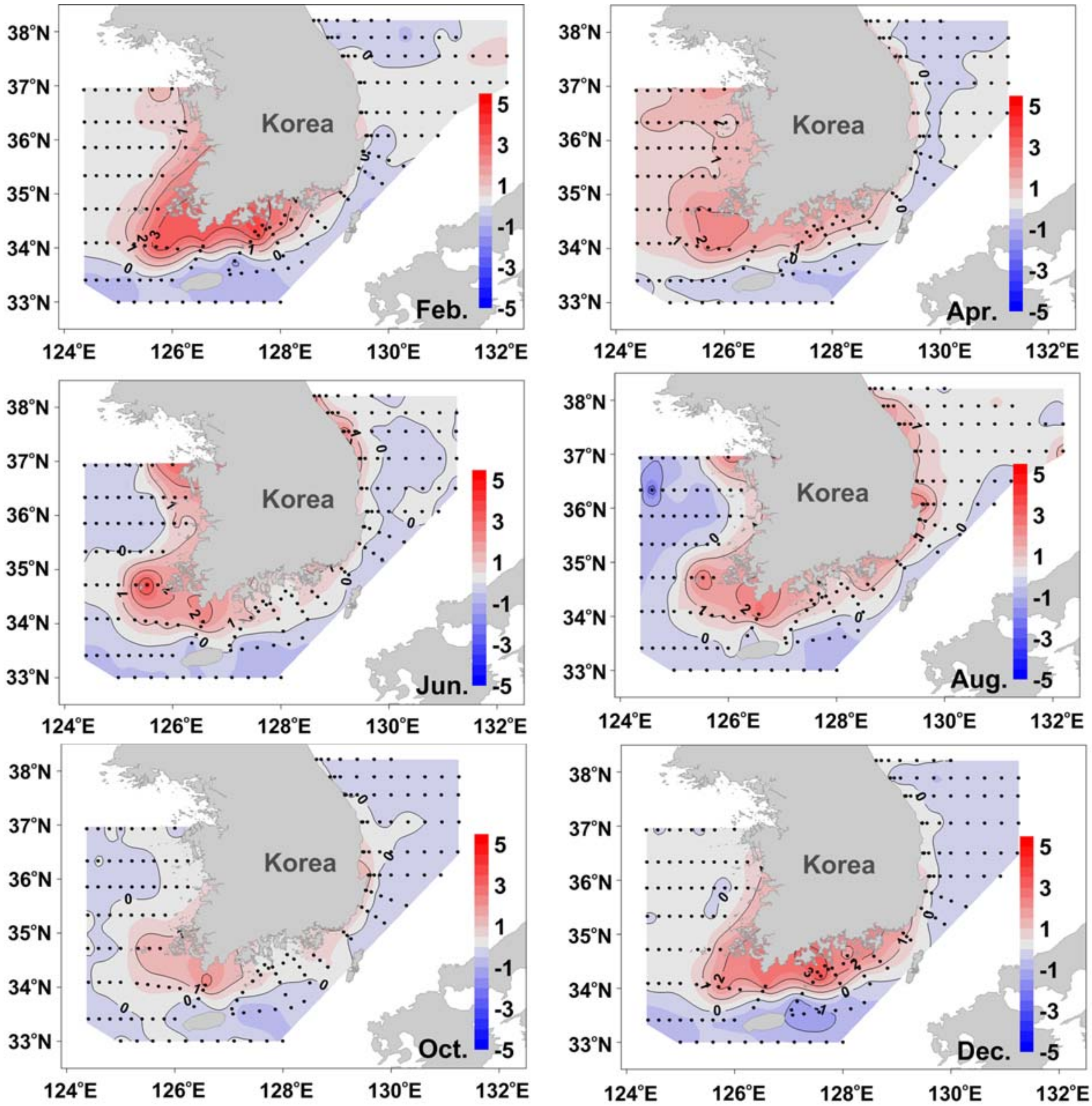

Fig. 4. Horizontal distribution of satellite SST biases in each measurement month for 30 years (1984~2013). Positive number represents a warm bias of satellite SST

There exists little significant difference between the satellite and in-situ SSTs in the EJS in terms of the mean SST and the long-term trend (Figure 8). The bias is almost same in the EJS with a magnitude of less than 0.5°C during whole period. The RMSE increases slightly during 30 years.

The SS and the YS exhibit greater variability of the mean SST compared with the EJS. The RMSE varies greatly in the range of 1~2°C. In the SS, the long-term trends of satellite and in-situ SSTs are respectively 0.013°C/year and 0.021°C/year (Figure 9). The satellite SST consistently shows a warm bias in the SS and YS until recently, when negative biases are shown. Particularly in the YS, the long-term trend of the satellite SST is -0.006°C, while the in-situ SST is 0.029°C (Figure 10). The satellite SST shows a warm bias of 0.5~1.0°C in 1980s, but a cold bias of about 0.5°C is shown in recent years. Despite the long-term bias variability, the overall RMSE is almost same as about 1.5°C during whole period.

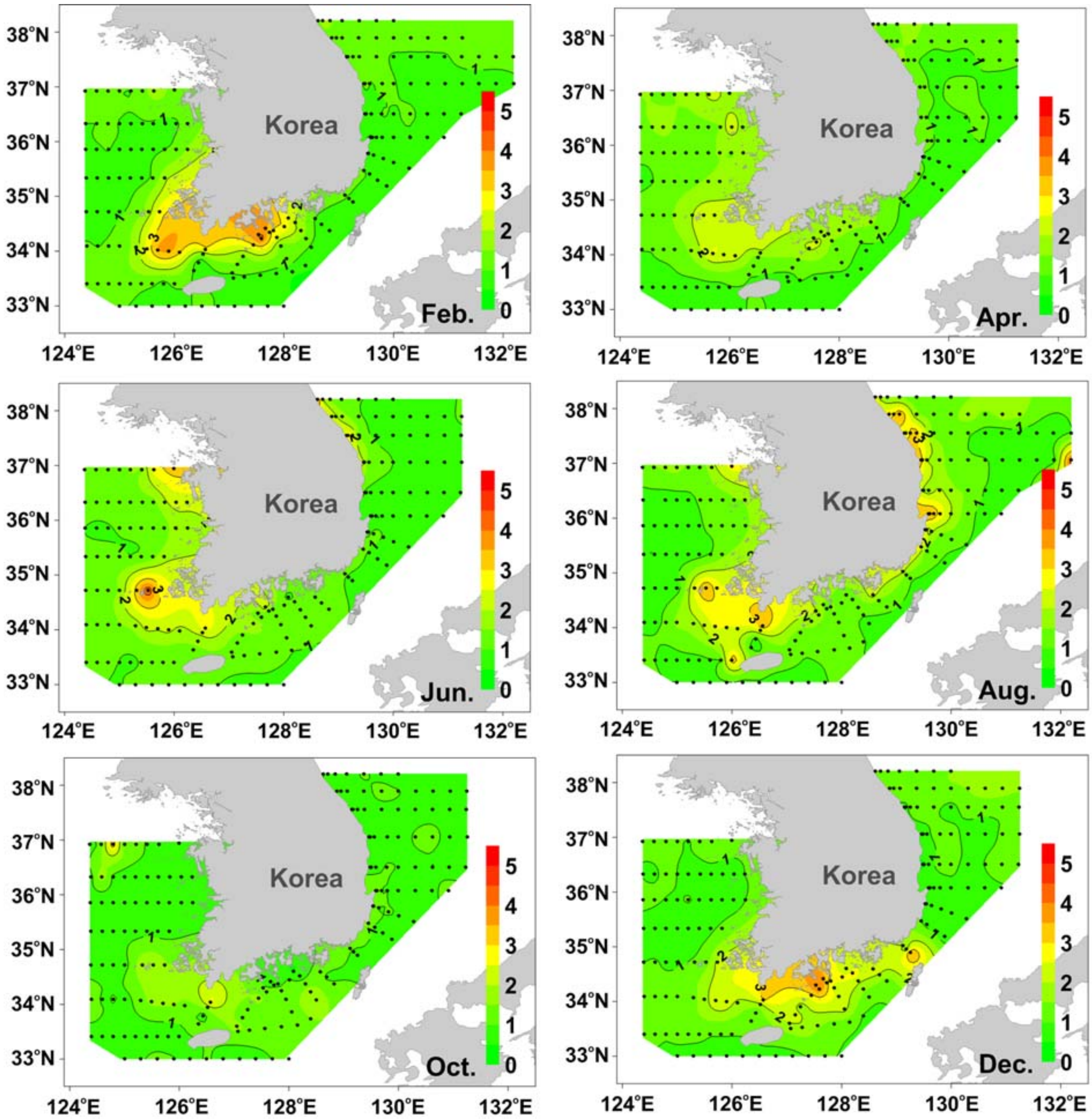

Fig. 5. Horizontal distribution of RMSE between in-situ and satellite SSTs in each measurement month for 30 years (1984~2013)

Comparisons of long-term SST trends

Satellite SST has been widely used to study global warming due to its good coverage. We compared the spatially averaged long-term SST changes in the seas around the Korean Peninsula (Figure 11). Linear trends in the time series of in-situ (0.024°C/year) and satellite (0.011°C/year) SSTs are found. The increasing rate of in-situ SST is close to the rate of 0.02°C/year reported in Min and Kim (2006) with the coastal oceanographic observation data from the Korea Oceanographic Data Center.

The time series of mean SSTs averaged over all regions show that the long-term trends are significantly different between in-situ and satellite SSTs (Fig. 11). The satellite SST shows a warm bias in 1980s, which turns into a negative bias in recent years. However, the RMSE shows little change. It can be suggested that the bias change and the different increase rate are mainly attributed to the satellite bias changes observed in the YS.

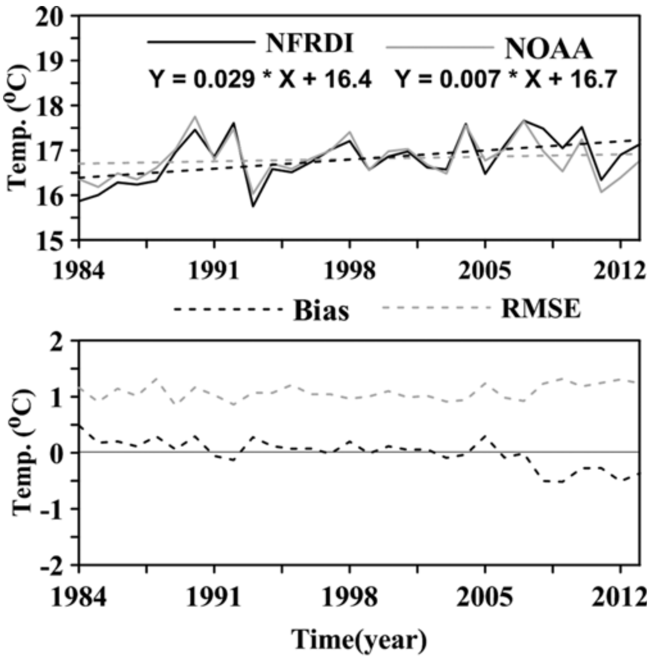

Fig. 6. (Upper) Time series of annual mean offshore SST from 1984 to 2013. Black and gray lines represent in-situ and satellite SSTs respectively. (Lower) Bias and RMSE between in-situ and satellite SSTs for the same period. Positive number represents a warm bias of satellite SST

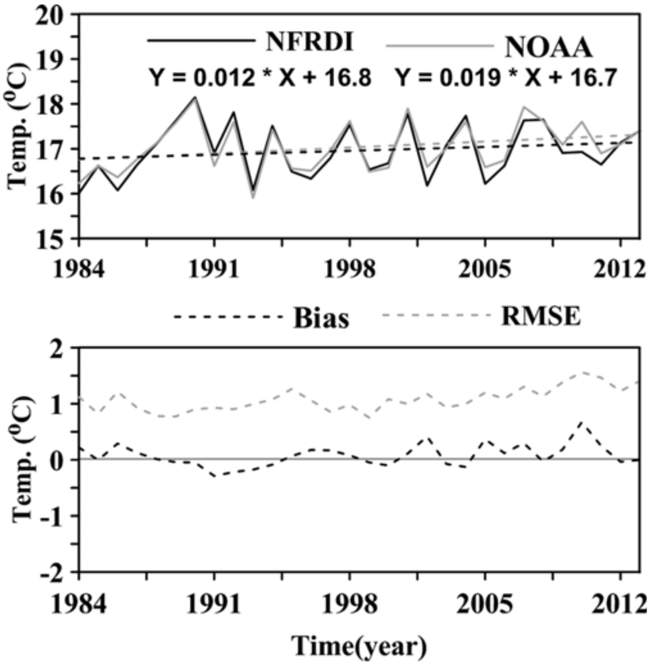

Fig. 8. (Upper) Time series of annual mean SST in the East/Japan Sea from 1984 to 2013. Black and gray lines represent in-situ and satellite SSTs respectively. (Lower) Bias and RMSE between in-situ and satellite SSTs for the same period. Positive number represents a warm bias of satellite SST

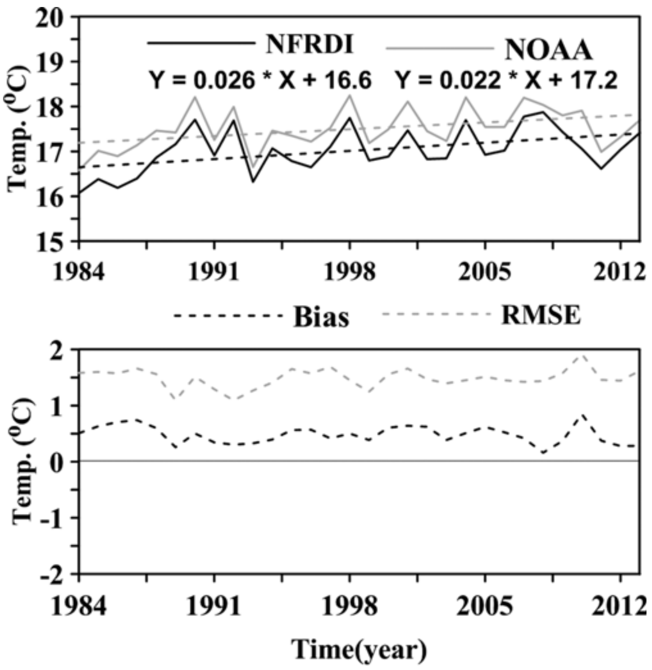

Fig. 7. (Upper) Time series of annual mean coastal SST from 1984 to 2013. Black and gray lines represent in-situ and satellite SSTs respectively. (Lower) Bias and RMSE between in-situ and satellite SSTs for the same period. Positive number represents a warm bias of satellite SST

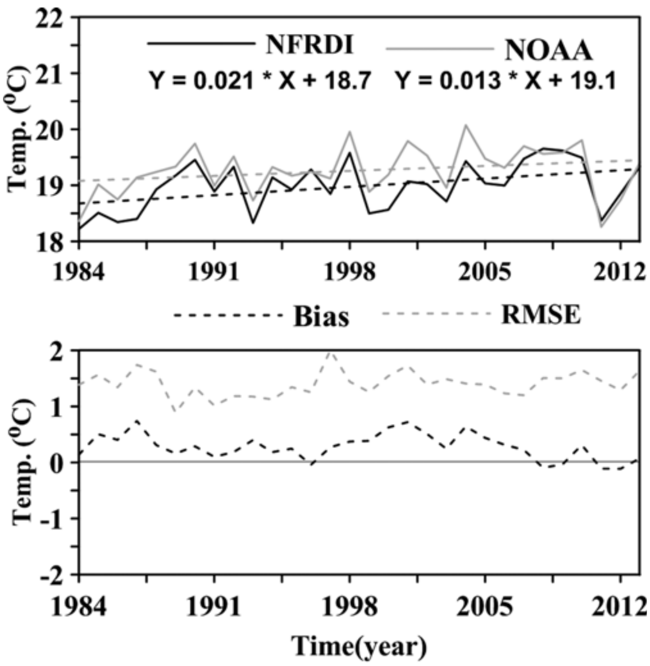

Fig. 9. (Upper) Time series of annual mean SST in the South Sea from 1984 to 2013. Black and gray lines represent in-situ and satellite SSTs respectively. (Lower) Bias and RMSE between in-situ and satellite SSTs for the same period. Positive number represents a warm bias of satellite SST

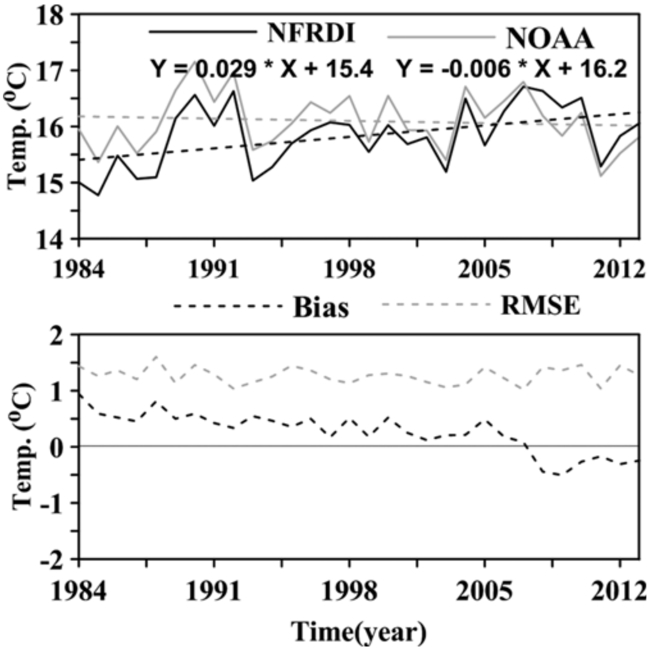

Fig. 10. (Upper) Time series of annual mean SST in the Yellow Sea from 1984 to 2013. Black and gray lines represent in-situ and satellite SSTs respectively. (Lower) Bias and RMSE between in-situ and satellite SSTs for the same period. Positive number represents a warm bias of satellite SST

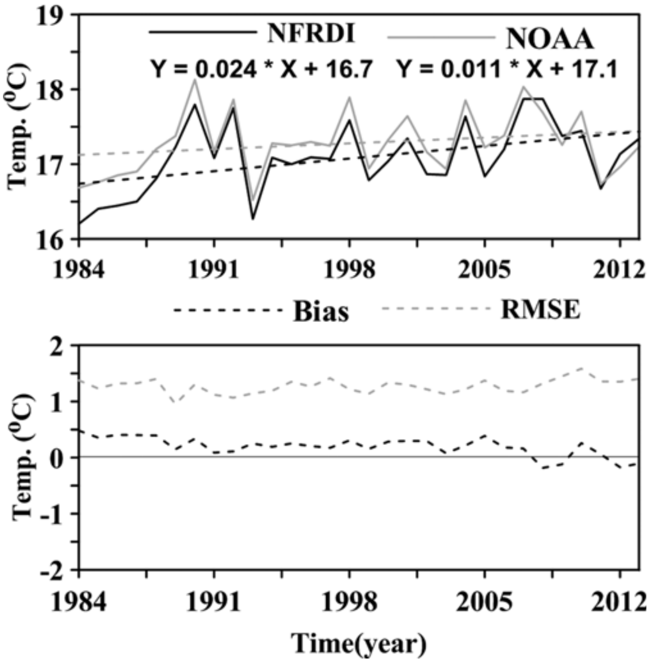

Fig. 11. (Upper) Time series of annual mean SST averaged in the seas around Korean Peninsula from 1984 to 2013. Black and gray lines represent in-situ and satellite SSTs respectively. (Lower) Time series of bias and RMSE between in-situ and satellite SSTs for the same period

4. Conclusion

Spatio-temporal differences in the seas around Korean Peninsula are found in the long-term comparison of satellite and in-situ SSTs from 1984 to 2013. The difference between the two SSTs is larger in the coastal area than in the offshore area. The RMSE of satellite SST is about 1°C in the offshore area and about 2~3°C in the coastal area, suggesting that a more careful analysis of satellite SST data is needed for the coastal area. Likewise, the satellite SST bias is less than 1°C in the offshore area and 1~3°C in the coastal area. The satellite SST bias in the coastal area is almost constant over the past 30 years, but in the offshore area, a warm bias in 1980s changes to a cold bias in recent years. The temporal analysis shows that the bias and the RMSE are small in spring and fall than in winter and summer.

In the EJS, the satellite SST is in good agreement with the in-situ SST and the bias is less than 0.5°C for the whole period. The RMSE is about 1.0°C throughout 1980s and 1990s, which slightly increases recently. The RMSE in the SS and the YS fluctuates in the range of 0.5~2°C. The satellite SST in the SS and the YS shows a warm bias, which changes to a cold bias in recent years. In particular, in the YS, the satellite warm bias of 0.5~1.0°C until 2006 turns into a cold bias of about 0.5°C in recent years. The change results in a long-term cooling trend for satellite SST in the region while in-situ SST shows a warming trend. Both in-situ and satellite SSTs show a warming trend in other seas as well. Despite the bias change, the RMSE in the YS is constant as 1.5°C during the entire period.

Overall, the satellite SST exhibits a warm bias in the past and a cold bias in these years. The long-term trends of in-situ and satellite SSTs averaged over the seas around the Korean Peninsula are respectively 0.024°C/year and 0.011°C/year and the difference is mainly affected by the bias change in the YS. The recent change of satellite SST in the YS should be carefully considered in studying long-term trends in the area. The possible reasons for the satellite bias change in the YS will be addressed in a future study.

Acknowledgements

This study is supported by the Korea Meteorological Administration Research and Development Program under the grant CATER 2012-2080 and partly by the project titled "Long term change of structure and function in marine ecosystems of Korea," which was funded by the Oceans and Fisheries, Korea.

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