The Feasibility of Using Re-analysis Data as Thermal Infrared Radiometric Calibration Reference

Yanan Xue[1, 2], Ning Wang [1], Lingling Ma [1], Xinhong Wang[1] , Kun Li[1] ,

1 Key Laboratory of Quantitative Remote Sensing Information Technology, Aerospace Information Research Institute, Chinese Academy of Sciences, Beijing 100094, China;

2 School of Optoelectronics, University of Chinese Academy of Sciences, Beijing 100049, China

Abstract

The re-analysis data can provide global gridded surface temperature, albedo, atmospheric profile and other parameters in continuous spatial and temporal dimensions. In order to reduce the cost and the complexity of calibration procedure, at the same time to increase the calibration frequency, it is a feasible way to use both the SST and atmospheric profile information extracted from the re-analysis data. However, one of the prerequisite is to check the accuracy of re-analyzed SST and consistency with other observations, and subsequently the reliability of the simulated top-of-atmosphere (TOA) based on the re-analysis data should also be verified. This study takes the ocean as research target to carry out the comparison and verification of SST and TOA brightness temperature(BT) from different sources, including the re-analyzed data from the European Center for Medium-Range Weather Forecast (ECMWF) ERA5, the buoys measured data, the satellite observations and related SST product. This study provides support for thermal infrared radiation calibration based on re-analysis data.

First, the comparison of ERA5 sea surface skin temperature(SST_{skin}) and ARGO buoy SST was carried out. Global Argo data in 2020 is used in research. The results show that the annual maximum RMSE between ERA5 SST_{skin} and ARGO SST is 0.50K, and the minimum RMSE is 0.45K. Next, comparisons between ERA5 SST_{skin} and MODIS SST were carried out, with both the daily data covering the whole global area. The results show that these data are highly consistent when the range of SST is big enough. The correlation coefficient between the two types of daily data is above 0.99, and the RMSE is 0.51K. Finally, ERA5 SST_{skin} and atmospheric profile data were used to simulate MODIS 31 band TOA BT, using MODTRAN atmospheric radiometric transfer model, and those simulations were compared with MODIS observations. The results show that the annual RMSE is 0.52K in the worldwide. Overall, it is feasible to use re-analysis data as thermal infrared radiometric calibration reference, and the expected radiation calibration accuracy is within 1.0K.

Introduction

The re-analysis data can provide long-term assimilation data with good consistency. In climate applications such as atmospheric analysis and surface environmental change monitoring, re-analysis data has been widely recognized. With the improvement of observation methods and the development of data assimilation model, re-analysis data can meet the needs of reference for radiation calibration。

Commonly used sources of reanalysis data products include European Centre for Medium-Range Weather Forecasting(ECMWF), National Centers for Environmental Predictions(NCEP), National Aeronautics and Space Administration(NASA) and Japan Meteorological Agency(JMA). These re-analysis data have differences in temporal resolution and horizontal resolution。The re-analysis data used in this study is the ECMWF Reanalysis v5(ERA5).

This article verifies the feasibility of using re-analysis data as thermal infrared radiometric calibration reference by comparing the SST and the TOA BT. The Argo buoy SST and MODIS SST are selected as verification data to compare ERA5 SST_{skin} on a global scale. MODIS TOA BT was selected as verification data to compare the simulation of ERA5 SST_{skin} and atmospheric profile data.

Data Description

- **ERA5 parameters[1]:**
  data on single levels: Skin temperature; Figure 1 shows the global SST_{skin} on June 1, 2020.
  data on pressure levels: Geopotential; Ozone mass mixing ratio; Specific humidity; Temperature
  * Horizontal resolution: 0.25°×0.25° * Temporal resolution: Hourly
  * Vertical resolution: 37 pressure levels * Vertical coverage: 1000 hPa to 1 hPa

- **Argo buoy SST[2]**
  The Argo buoy SST comes from China Argo Real-time Data Center(CARDC).
  Figure 2 shows the global distribution of Argo buoys. Argo buoy SST in 2020 were collected.

- **TERRA MODIS SST[3]**
  The MODIS SST used in this article derived from long-wave (11-12 μm) thermal radiation. MODIS SST on the four days of the spring equinox, summer solstice, autumnal equinox, and winter solstice in 2020 were collected.

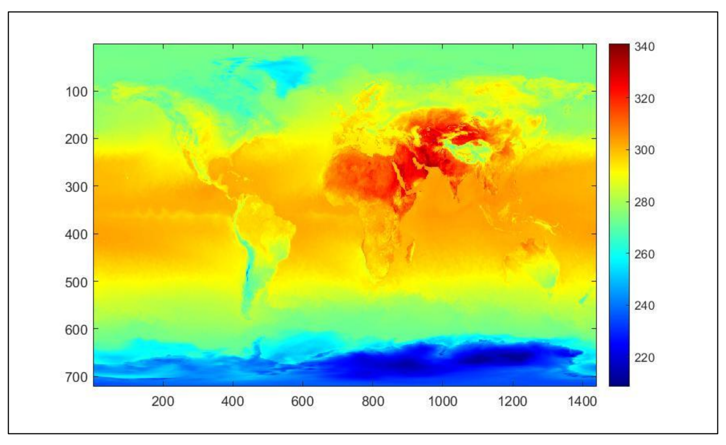

Figure 1: The global SST_{skin} on June 1, 2020

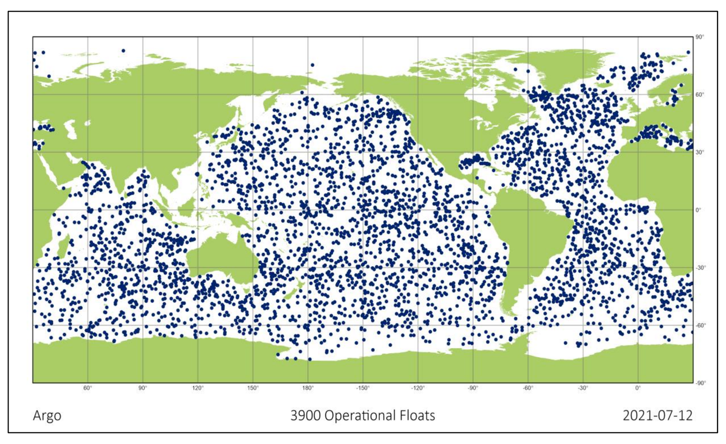

Figure 2: The global distribution of Argo buoys

Evaluation Indicators

Several metrics are introduced to reveal the accuracy of ERA5 SST_{skin} and TOA BT simulation value, including the mean bias error (MBE), mean absolute error (MAE), standard deviation (STD) and root mean squared error (RMSE).

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(S_i - I_i) \qquad MAE = \frac{1}{n}\sum_{i=1}^{n}(|S_i - Q_i|)$$

$$STD = \sqrt{\frac{1}{n}\sum_{i=1}^{n}[(T_i - Q_i) - \overline{(T-Q)}]^2} \qquad RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(T_i - Q_i)^2}$$

RESULT 1: Argo SST with ERA5 SST_{skin}

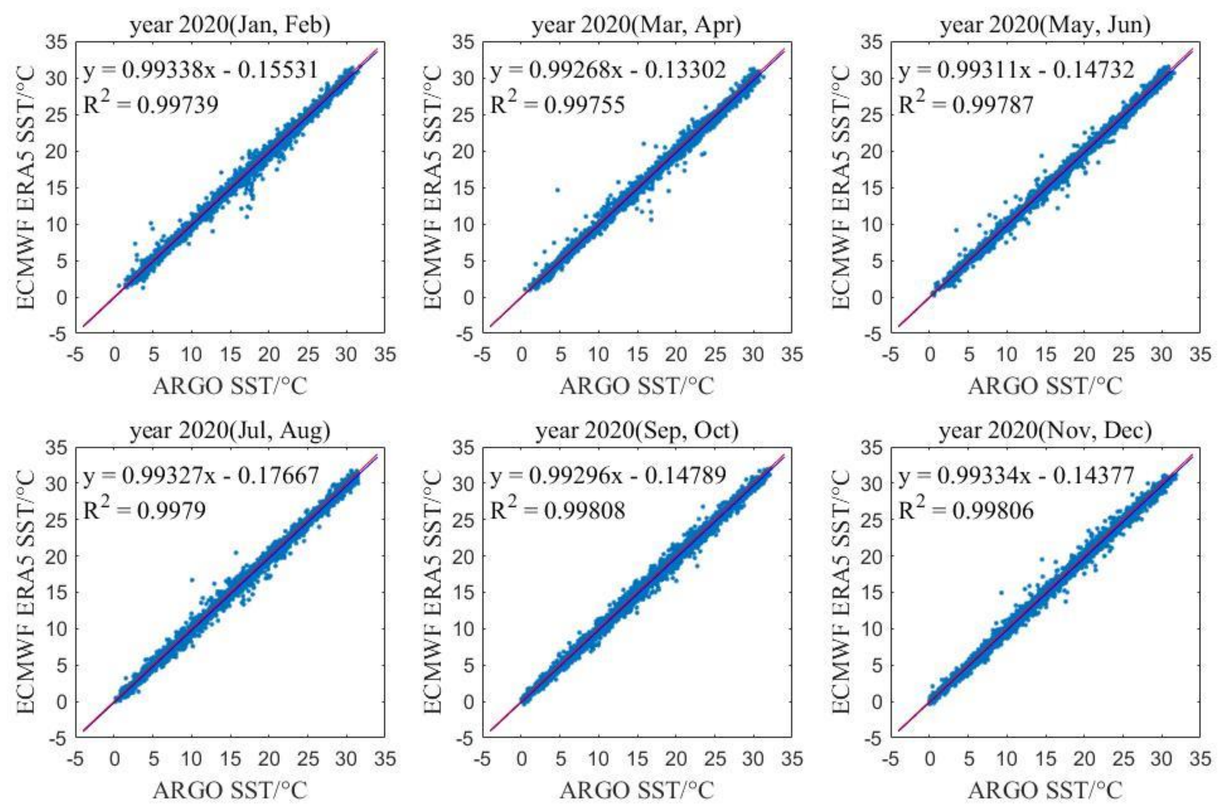

Figure 3: Scatter plot of Argo SST with ERA5 SST_{skin}

The scatter plot in Figure 3 shows that there are a few matchups with significant bias, but that there is good quantitative agreement between ERA5 SST_{skin} and Argo SST. All the coefficient of determination(R^2) between ERA5 SST_{skin} and Argo SST are over 0.99. The slope of the line fitted by least square method is between 0.992 and 0.994. There is no obvious difference in the monthly deviation between ERA5 SST_{skin} and Argo SST.

Table 1 shows the statistics of the ERA5 SST_{skin} minus Argo SST differences. The number of data in each group exceeds 16,000. The MBE is between -0.30K and -0.24K. The MAE is between 0.34K and 0.38K. The STD is between 0.37K and 0.41K. The RMSE is between 0.45K and 0.50K. Overall, the deviation of SST_{skin} relative to Argo SST is stable.

Table 1: Statistics of ERA5 SST_{skin} minus Argo SST. The unit is K.

Time	No. of matchups	MBE	MAE	STD	RMSE
2020(Jan, Feb)	16893	-0.2856	0.3704	0.4059	0.4963
2020(Mar, Apr)	16673	-0.3005	0.3838	0.3872	0.4902
2020(May, Jun)	18563	-0.2820	0.3699	0.3771	0.4709
2020(Jul, Aug)	18389	-0.2762	0.3672	0.3799	0.4697
2020(Sep, Oct)	18042	-0.2698	0.3612	0.3778	0.4643
2020(Nov, Dec)	17837	-0.2462	0.3411	0.3819	0.4544

RESULT 2: MODIS SST with ERA5 SST_{skin}

The scatter plot in Figure 4 show that even for a single day of observation, the global MODIS SST has a wide range. The R^2 between ERA5 SST_{skin} and MODIS SST is 0.998. The slope of the line fitted by least square method is 0.993. There is a negative deviation between ERA5 SST_{skin} and MODIS SST.

Table 2 shows the statistics of the ERA5 SST_{skin} minus MODIS SST differences. The number of matching scatter points is 19268. The MBE is -0.34K. The MAE is 0.40K. The STD is 0.37K. The RMSE is 0.51K. ERA5 SST_{skin} values are generally in good agreement with the corresponding MODIS SST data.

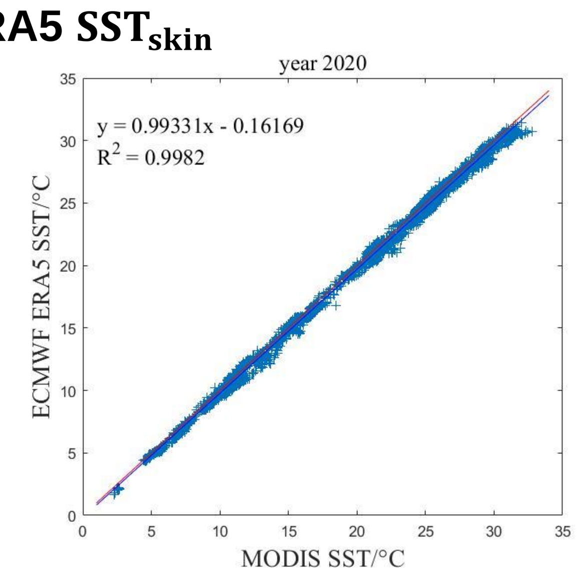

Figure 4: Scatter plot of MODIS SST with ERA5 SST_{skin}

Table 2: Statistics of ERA5 SST_{skin} minus MODIS SST. The unit is K.

Time	No. of matchups	MBE	MAE	STD	RMSE
2020	19268	-0.3429	0.3970	0.3752	0.5083

RESULT 3: MODIS TOA BT with TOA BT simulations

The scatter plot in Figure 5 shows the TOA BT simulations and MODIS TOA BT are also in good agreement. The R^2 between TOA BT simulations and MODIS TOA BT is 0.997. The slope of the line fitted by least square method is 1.005. Due to the addition of atmospheric conditions, the location of scattered points has changed significantly compared to Figure 4.

Table 3 shows the statistics of the TOA BT simulations minus MODIS TOA BT differences. The MBE is -0.35K. The MAE is 0.43K. The STD is 0.39K. The RMSE is 0.52K.

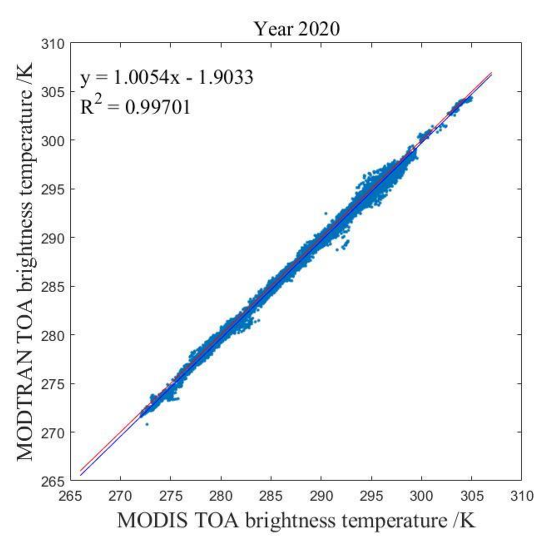

Figure 5: Scatter plot of MODIS TOA BT with TOA BT simulations

Table 3: Statistics of TOA BT simulations minus MODIS TOA BT. The unit is K.

Time	No. of matchups	MBE	MAE	STD	RMSE
2020	19268	-0.3483	0.4257	0.3894	0.5225

Future Work

- In the future, more work is planned to analyze the dependence of ERA5 SST_{skin} and TOA BT simulations on various influencing factors, such as wind speed, water vapor, clouds and aerosol optical depth.
- We anticipate that further comparison work in the future will be narrowed down to the region，such as the Pacific and the Atlantic, the ocean area surrounding China and Low-latitude or mid-high latitude ocean area.

Conclusions

In this study, the ECMWF ERA5 product is evaluated from different aspects, including SST_{skin} and TOA BT. Overall, ERA5 SST_{skin} have -0.3K ~ -0.24K MBE and 0.45K~0.5K RMSE around the world when compared to Argo buoys, and it have -0.34K MBE and 0.51K RMSE around the world when compared to MODIS SST. Using ERA5 SST_{skin} and atmospheric profile data to simulate TOA BT have -0.35K MBE and 0.52K RMSE when compared to MODIS observations. We are initially convinced that it is feasible to use re-analysis data as thermal infrared radiometric calibration reference within a certain accuracy range.

Reference

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