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STUDY ON EVALUATION METHOD OF SEA SURFACE TEMPERATURE PERFORMANCE OF A SHIPBOARD RADIOMETER

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Abstract. *Sea surface temperature (SST) is an important ocean parameter and is a key indicator of climate change. At present, sea surface temperature is retrieved from brightness temperatures observed by the satellite-borne radiometer, and then using the ship-borne radiometer measurements verifies the retrieved results. There is a high requirement for the accuracy of the ship-borne radiometers. The measurement accuracy of the actual temperature at sea is verified by the following two methods. One is to use non-contact temperature sensors to compare; however, because of the harsh conditions of the sea, this cannot get the true value of the sea surface. The second is to compare with the contact temperature sensor; however, its measurement is the bulk temperature rather than the sea surface skin temperature. Therefore, an improved skin-layer model is proposed. The model firstly uses the neural network algorithm to calculate the sensible heat, latent heat and net long wave radiation, and then uses the skin-layer model to convert the skin SSTs into bulk SST, then compare with CTD temperature data. The temperature measurement accuracy of CTD is 0.02° C, and the root meam square of the self-developed ship-borne radiometer SSTs compared with CTD SSTs is 0.24K.*
Keywords: Sea surface skin temperature, Skin-layer temperature model, Infrared radiometer, The neural network algorithm

1. **Introduction.** Sea surface temperature (SST) is one of the most important parameters in the global air-sea system. It is an important parameter of the ocean, and also is widely used in the description of ocean circulation and kinetic studies of the upper air-sea heat exchange. The water at the uppermost surface of the ocean, the "skin", is typically a few tenths of a degree Celsius cooler than the "bulk" water a few decimeters below. Due to the variations in net heat .12flux at the atmosphere-ocean interface, this difference is highly variable. Robinson et al. [1] state that an accuracy of 0.2 °C in satellite measured SST is necessary for global climate models. This suggests that rather than regressing satellite measurements against bulk measurements (using temperatures from drifting buoys) as is done presently, in situ radiometric measurements should be used to improve satellite validation and the correction for atmospheric attenuation of the infrared signal from the skin of the ocean.

In earlier experiments (Grassl and Hintzpeter [2]; Grassl [3]; Schlüessel et al. [4,5]), in situ radiometric SST measurements have been made for studies relating to air-sea heat flux. Barton et al. [6] state that they studied the calibration performance of seven infrared radiometers and compared them with each other. Seven kinds of infrared radiometers are the Marine-Atmospheric Emitted Radiance Interferometer (M-AERI), the Infrared SST Autonomous Radiometer (ISAR-5), the Scanning Infrared Sea Surface Temperature Radiometer (SISTeR), the Jet Propulsion Laboratory (JPL) Near-Nulling Radiometer, the Calibrated Infrared In situ Measurement System (CIRIMS), the DAR011 radiometer, TASCO THI-500L noncontact infrared radiometers. Those radiometers were mounted alongside each other on the R/V *Walton Smith* for an intercomparison under seagoing conditions. The ship results confirm that all radiometers are suitable for the validation of sea surface temperature, and the majority are able to provide high quality data for the more difficult validation of satellite derived sea surface temperature, contributing less than 0.1K to the error budget of the validation.

There are several reasons why in situ validation measurements for satellite-retrieved SST are necessary. Of primary importance is the attenuation and reradiation of radiant energy by atmospheric water vapor, which is the single most significant source of error in determining SST from space. However, the shipborne radiometer measured temperature is accurate without the researchers to evaluate it. Here we will use the temperature of the instrument CTD in situ to evaluate the temperature of the shipborne radiometer. However, there is a temperature difference between the bulk temperature and the skin temperature [7], as shown in Figure 1, so we need to use a method of conversion from skin SSTs to bulk SSTs. One method to do this is to simply bias correct the shipborne radiometer observations with respect to co-located in-situ bulk SST measurements. A more attractive approach is to model the temperature difference across the skin layer.

The purpose of this paper is going to present a skin-layer model, it can convert the skin SSTs into bulk SSTs, and then use the contact sensor data to evaluate it. The method of building the skin-layer model takes account of the coupling effect of ocean atmosphere, including the effect of wind speed, air sea heat exchange on the temperature difference, and it can calculate the real time difference between seawater temperature and skin temperature. This study improves the accuracy verification of in-situ shipborne infrared radiometer.

The full text is divided into 6 chapters, the main contents of each chapter are as follows.

The first chapter describes the significance and necessity of the shipborne radiometer SST, introduces the present situation of study on temperature accuracy of sea surface, and the research purpose and research content of this paper.

The second chapter gives the skin-layer model used in the paper and the measurement of the skin effect.

The third chapter gives the measured data needed in the paper and how to obtain them.

The fourth chapter gives the calculation method of the required input quantity Q in the skin-layer model, that is, the net heat flux.

The Chapter Five gives the results of the model and the corresponding analysis.

The Chapter Six gives the results of this study.

Figure 1 illustrates schematically relationships between SST_{int}, SST_{skin}, $SST_{sub\text{-}skin}$ and SST_{depth}. Figure 1(a) shows the characteristic thermal structure at night, when moderate to strong winds prevail during the day that homogenize the temperature in the upper water layers. $SST_{sub\text{-}skin}$ is similar to SST_{depth} at all depths but is characteristically warmer than the cooler SST_{skin}. Figure 1(b) depicts the characteristic situation for late morning-early afternoon following a period of light/absent wind and insolation.

2. Models.

Various models have been proposed to describe the temperature difference across the oceanic skin layer and for our purpose we require one which is applicable across all ocean conditions.

2.1. The skin-layer model.

In order to realize the calibration of remote sensing data, one method to do this is to simply bias correct the satellite observations with respect to co-located in-situ bulk SST measurements. A more attractive approach is to model the temperature difference across the skin layer. Various researchers have proposed skin layer models [8,9], with the skin represented as a conduction layer. Below this layer the ocean is considered to be well mixed at night (during the day a temperature gradient can build

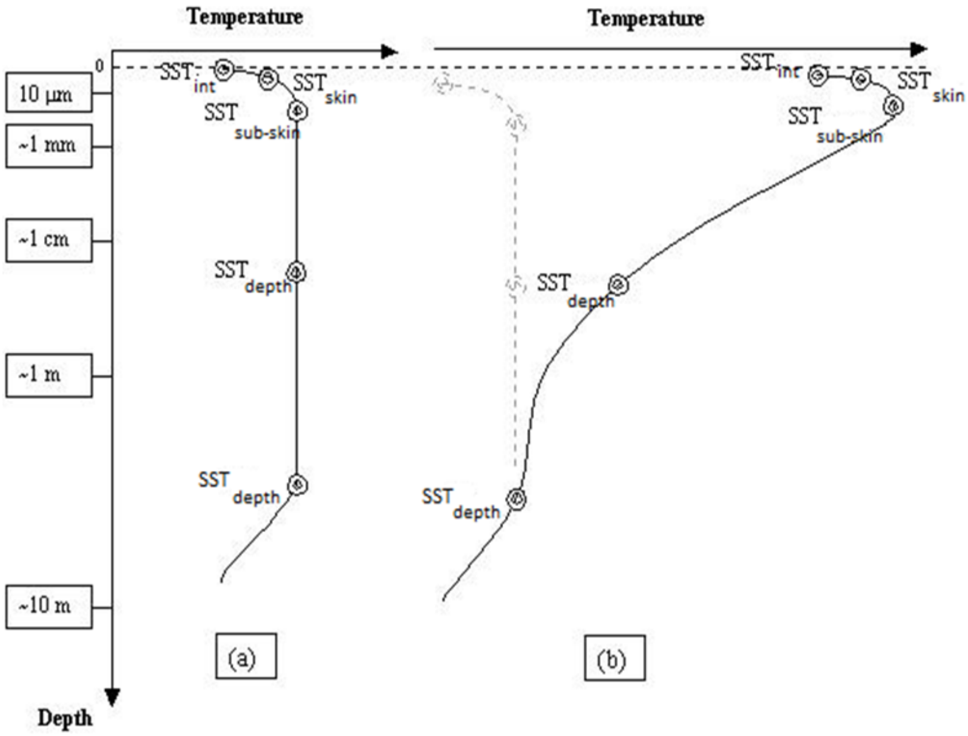

FIGURE 1. Idealized temperature profiles of the near surface layer (~10 m depth) of the ocean during (a) nighttime and daytime during strong wind conditions and (b) daytime low wind speed conditions and high insolation resulting thermal stratification of the surface layers

up in the mixed layer known as the diurnal thermocline). Depending on the direction of the heat flux between the ocean and atmosphere [10], the skin SST can either be cooler or warmer than the underlying bulk SST value in a range of around ±1K.

Saunders [11] derived a theoretical model for forced convection conditions by treating the skin layer as a fixed conduction layer whose depth depends on windspeed. It has the following form:

$$\Delta T = \frac{\lambda Q v}{k \rho c_p v_*} \tag{1}$$

where Q represents the heat flux out of the ocean, v_* is the friction velocity in water, κ is the thermal diffusivity, ρ is the density of water, c_p is the specific heat capacity of water, v is the kinematic viscosity, and λ is a dimensionless constant.

Fairall [12] extended the model to cover low wind speed conditions by redefining λ as a function of flux and friction velocity:

$$\lambda = \lambda_0 f(v_*, Q) \tag{2}$$

where λ_0 is the value that λ will tend to as the free convection regime is approached. λ_0 has been estimated by various authors to be between 5 & 10. For the night-time a value of 4 was found to be optimal, and for the day-time a value of 7.5. Different values of λ_0 are used for day and night as different SST retrieval coefficients are used for the different day regimes. We can use λ_0 as a tuning constant to remove the residual bias between in-situ buoy SSTs and converted satellite bulk SSTs.

2.2. **The skin effect.** The skin effect occurs due to the energy exchange between the ocean and the atmosphere. The skin layer is generally around 0.5mm thick depending on the wind mixing and the heat transfer across it takes place by molecular conduction. The net flux through the skin is composed of four fluxes: latent, sensible, infrared and solar (short-wave). Due to the very small thickness of the skin layer only a small attenuation of the short-wave radiation takes place across it and the last term of the flux budget is therefore often omitted in considerations involving the skin layer. Depending on the direction of the heat flux the skin may be either warmer or colder than the mixed layer underneath. However, the heat flux across the skin layer is on average out of the ocean resulting in a skin that is cooler than the mixed layer.

It is found that the larger the sea surface wind speed is, the smaller the temperature difference between the sea surface temperature and the sea water temperature is; if ignoring low wind speed, the smaller the deviation and standard deviation between the sea surface temperature and the sea water temperature will reduce.

The magnitude of this skin effect increases both with net surface heat flux and the thickness of the conduction layer. Wind speed influences the skin effect in two competing ways: increasing wind speed increases total surface heat flux which tends to increase the skin effect, but also thins the conduction layer, which tends to reduce the skin effect [13]. Generally it is predicted that the magnitude of the skin effect will increase with net surface heat flux (Q) at a given wind speed (u) and decrease with increasing wind speed for a given heat flux.

3. **Data.** Our study area is the Yellow Sea, measurements were taken from September 2016 to November 2016, and the selected measurement range is 35°43′ ∼ 38°02′N, 119°10′ ∼ 122°17′E.

The meteorological data obtained from the observation station were wind speed (10m), air temperature (2m), air specific humidity (2m) and sea surface temperature and rapid profiling conductivity, temperature and depth (CTD) measured sea water temperature.

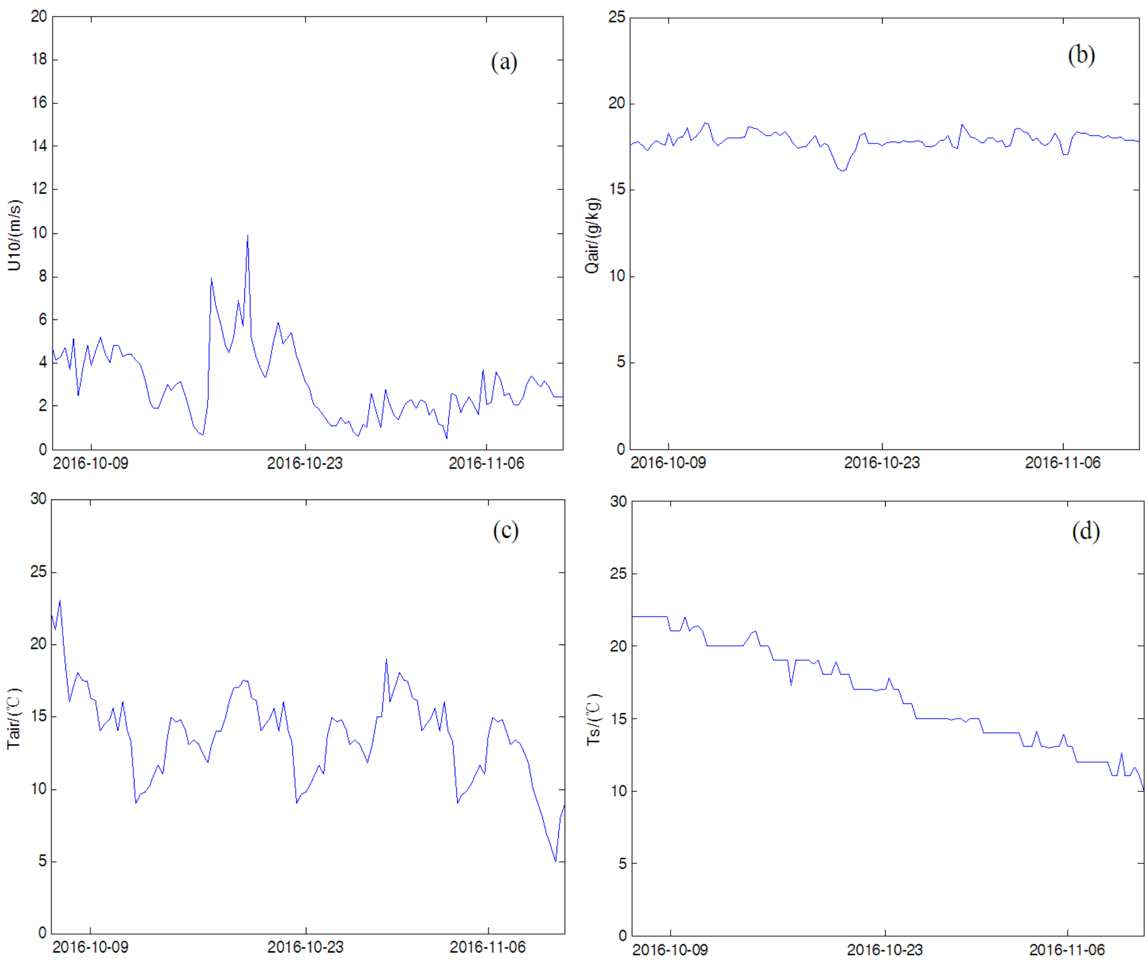

Figure 2. Time series plots of daily averaged values of meteorological parameters

Figure 2 shows the daily average time series of meteorological data from in-situ measurements.

We need to calculate the net surface heat flux in the skin-layer model. First, we use the neural network model to calculate the turbulent heat flux, and then install the radiometer on a buoy of about 4m above sea level to measure the net longwave radiation flux R_{nl}. The formula for calculating the net heat flux is:

$$Q = H_S + H_L + R_{nl} \tag{3}$$

where H_S is sensible heat flux, H_L is latent heat flux, R_{nl} is infrared radiation flux.

4. **Neural Network Algorithm.** At present, bulk formula is widely used to calculate turbulent heat flux, such as COARE 3.0 algorithm; however, due to the application of simplified and statistical algorithms, the error accumulation of heat flux calculation is increased, so we want to use the neural network algorithm to solve the nonlinear mapping on the advantages of the heat flux calculation. We use neural network to establish the relationship between the sea surface meteorological parameters and sensible and latent heat fluxes. In order to reduce the error accumulation in the calculation of heat flux, we need to improve the accuracy of the result of retrieve.

In this scheme, we use four parameters respectively which are sea surface temperature, air temperature, humidity and wind speed, and they are matched with the latent heat and sensible heat flux. After testing and matching the data, we can get 1000 matching data sets. In order to improve the training rate, the above data are preprocessed.

1) Standardized treatment, in order to avoid the phenomenon that the average variance of the network does not decrease with the increase of the number of iterations.

2) The main factor analysis is used to make the input vector orthogonal to reduce the redundant data, improve the effectiveness of the training data and shorten the training cycle, so as to reduce the time and times of network training. Part of the matched data is used to establish and train the neural network model, and another part is used to retrieve and test the model.

The neural network model contains two hidden layers and the number of nodes is determined by the experimental results. The input parameters are the sea surface temperature, air temperature, air specific humidity and wind speed; the output parameters are latent heat and sensible heat flux.

We randomly selected the latent heat and sensible heat flux data for one month from GSSTF2, established the model with four input parameters: the sea surface temperature, air temperature, specific humidity and wind speed. And then use the obtained relationship to reverse the flux results of other months. A comparison of heat flux in ANN method with Bulk method is shown in Table 1.

Table 1. The comparison of heat flux in ANN method with Bulk method

Method	Sensible Heat		Latent Heat	
	Bias	RMS	Bias	RMS
Bulk method	-0.66 ± 3.4	9.05 ± 4.6	-1.72 ± 9.5	23.7 ± 4.0
ANN method	0.26 ± 2.6	7.54 ± 3	-0.31 ± 6.5	20.1 ± 3.2

We compare the monthly mean latent heat flux and sensible heat flux results of the Bulk method and the ANN method with the GISSTF2 data. The deviation of the sensible heat flux by the ANN method is $0.4 \pm 0.8\text{W/m}^2$ smaller than that of Bulk method, and the root mean square difference is $1.5 \pm 1.6\text{W/m}^2$ versus that of Bulk method. Obviously, the results obtained by ANN are better than those of Bulk, which may be due to the fact that the model directly establishes the relationship between the reverse parameters and the flux, reducing the calculation error, thus improving the accuracy of reverse.

5. **Results.** Based on the results from the previous section, we use the obtained heat flux and wind data to drive the skin-layer model to calculate the difference between the skin temperature and bulk temperature. The results are shown in Figure 3.

Figure 3 shows the behaviour of the skin-layer model over a range of time. The example is for night-time and has been compiled using 1000 matchups of CTD SSTs with shipborne radiometer SSTs. The calculated temperature difference is in the range 0.06-0.26K.

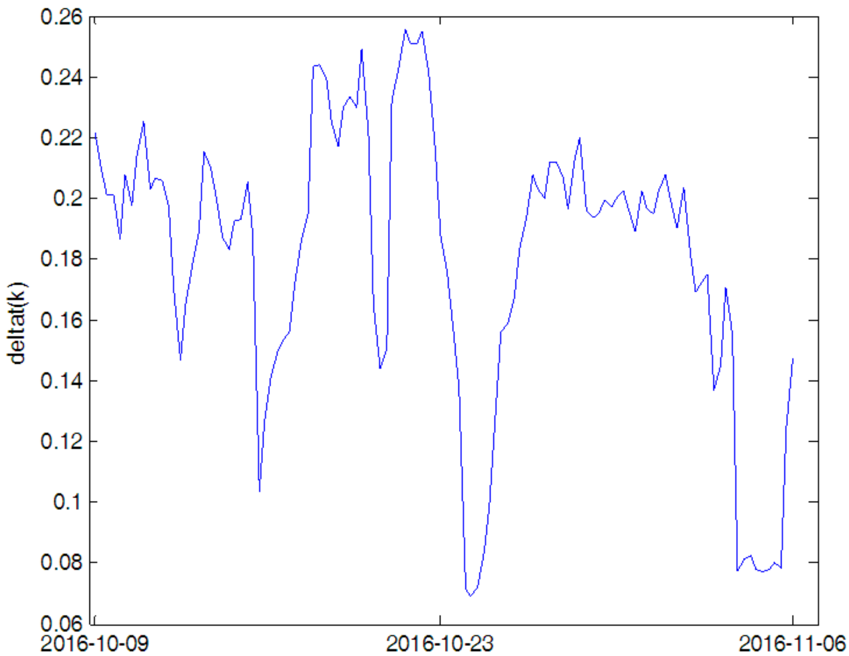

FIGURE 3. Graph showing delta t between the skin temperature and bulk temperature

6. **Conclusions.** In the present paper, it has been shown that the skin models account for a positive impact of between 0.01 to 0.03 in the standard deviation of the ship borne radiometer-CTD SSTs difference. In keeping with this small impact it has been shown that once the level of noise in the skin retrieval is raised the skin effect is masked out. The skin layer model predicted a mean bulk-skin SST difference of about +0.24K, whilst the observations were positively biased and exhibited a larger range. Extend this type of study to other locations in the Yellow Sea (deep water) or other offshore locations [14]. Because air-sea interactions can be highly dependent on wave conditions, the current data taken in shallow water may not be representative of conditions in deep water.

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