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A Study on Bulk and Skin temperature Difference using Observations from Atlantic and Pacific Coastal Regions of United States

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ABSTRACT

Analysis of bulk-skin sea surface temperature (SST) difference form the west and east coasts of United States is presented using the data collected from three field experiments. These experiments were conducted at offshore Duck, North Carolina and in the Monterey Bay of the California coastal region. Bulk SST measurements were made using conventional thermistors from a depth of one meter below the sea level. Infrared radiometers were used to measure the surface skin SST. Depending on measurement depth and prevailing conditions, the bulk SST can differ from skin SST by few tenths of a degree to *O*(1°C). Difference between bulk and skin SST arise from cools skin and warm layer effects. Bulk-skin SST difference (ΔSST) estimated from east coast observations varied from -0.46°C to 1.24°C. Here, the bulk SST was higher than skin SST most of the time during the observations. This indicates cool skin effect was the dominant factor determining the ΔSST in the east coast. For wind speeds less than 4 m s^{-1}, we also noticed an increase in ΔSST. Additionally, for low winds (< 4 m s^{-1}) ΔSST also varied diurnally with the occurrence of generally higher ΔSST in the nighttime in comparison with daytime. Moreover, increase in downwelling longwave radiation reduced the bulk-skin SST difference. ΔSST calculated from the observation in the Monterey bay varied between ~2.3° and ~-2.3°C. This was higher than the variability ΔSST observed at the east coast. Moreover, ΔSST variability observed at west coast was independent of wind speed.

Keywords: Sea surface temperature, Cool skin effect, Bulk-skin SST difference

1. INTRODUCTION

Sea surface temperature (SST) measurements are crucial for quantification and modelling of a number of oceanographic and atmospheric processes such as oceanic heat content, ocean circulation, air-sea interaction, and cyclogenesis. SST measurement accuracy are often determined by the method of observation. Conventional measurement of SST using research vessels and buoys records the temperature of the seawater a few meters below the surface typically ranging from one to five meter. This temperature is often referred as bulk SST. However, the temperature at the air-sea interface known as skin SST, sensed by a radiometer is the more relevant quantity that must be used for the atmospheric and oceanographic applications. Depending on measurement depth and prevailing conditions, the bulk SST can differ from skin SST by few tenths of a degree to *O*(1°C)[1, 2, 3, 4, 5, 6]. This difference in bulk and skin SST is governed by two processes known as warm layer and cool skin effects[1, 3, 4, 5]. The cool skin layer of the ocean is produced by the combined cooling effects of net

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longwave radiation, sensible heat flux, and latent heat flux. The surface skin layer of the ocean, much less than 1-mm thick[1, 5, 7, 8], is nearly always cooler than the underlying water because heat flux is generally directed outward from the ocean to atmosphere. Warm layers occur during the day when temperature stratification caused by the absorption of solar radiation is sufficiently strong to suppress shear induced mixing from below. Understanding the bulk-skin SST difference (ΔSST) is imperative for applications such as air-sea exchange of heat and gases [1], electromagnetic ducting research[9] and validation of satellite SST retrievals[4]. Our current understanding on the cool skin and warm layer effects are based on the observations made from the open ocean[1,4]. This may not be representative of the bulk-skin SST difference in the coastal regions. In this context, this study evaluates the bulk-skin SST difference observed at coastal regions of United States using the data collected during three field experiments.

2. EXPERIMENTS AND DATA

For this analysis, we used the bulk and skin SST data collected during three field experiments conducted at East and West coasts of United States. The first field experiment, named Coupled Air-Sea Processes and Electromagnetic ducting Research (CASPER) was conducted offshore Duck, North Carolina during October-November 2015. During the CASPER, we employed various ocean and atmospheric observations platforms including two research vessels *R/V Hugh R Sharp* (Hereinafter *Sharp*) and *R/V Atlantic Explorer* (Hereinafter *Explorer*). Figure 1a shows the *Sharp's* cruise track during the experiment. CASPER observations were limited within ~ 100 km from the shore. SST data from the *Sharp* are used here to investigate the bulk-skin SST difference observed at East Coast. Bulk SST measurements are from approximately one meter below the sea surface. An Integrated Infrared SST Autonomous Radiometer (ISAR) is used for the skin SST measurements. ISAR is a single channel radiometer (9.6-11.5 µm spectral band pass) capable of measuring *in situ* sea surface skin temperature to an accuracy of 0.1 K. Further details about ISAR can be found elsewhere [10, 11]. We also use the wind speed data from the *Sharp's* bow mast sonic anemometer installed ~12 m from the mean sea level. Since no broadband radiation measurements were available onboard *Sharp*, we use the downwelling longwave radiation data from the *Explorer*, which was making synchronized measurements with *Sharp*. During CASPER-East measurements, the ships were normally within ~50 km from each other. Hence, it is assumed that the net radiation flux observed at the *Explorer* is comparable to that at *Sharp*.

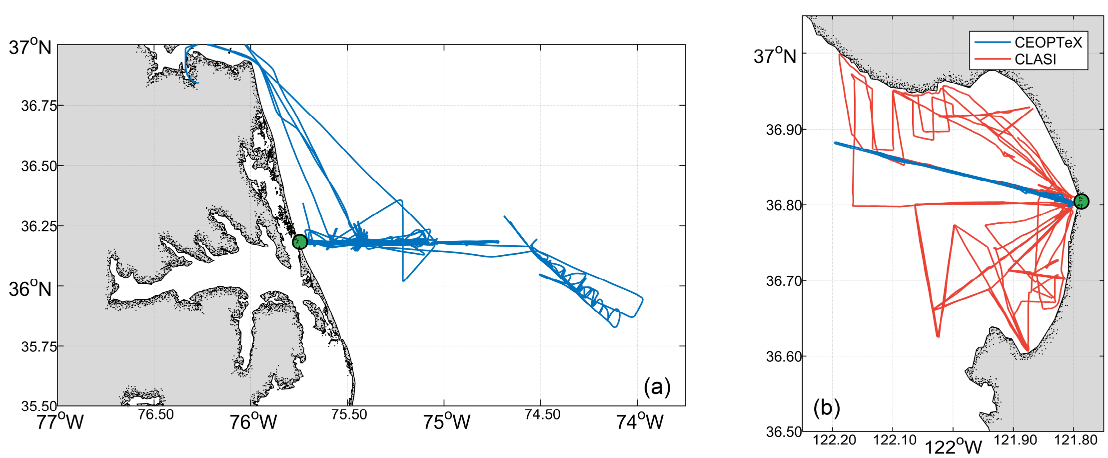

Figure 1: Cruise track of (a) *R/V Hugh R. Sharp* during CASPER-East and (b) *R/V John H. Martin* during CEOPTeX (blue) and CLASI (red).

SST data from the West Coast is collected during two field experiments: (1) Coastal Electro-Optical PorpagaTion eXperiment (CEOPTeX) and (2) Coastal Land-Air-Sea Interaction (CLASI). Both of the experiments were conducted in the Monterey Bay region of the Coastal California during May-June 2016. The research boat, *R/V John H. Martin* (Hereinafter *Martin*) is deployed for the observations during these experiments. Figure 1b shows the cruise track of *Martin* during CEOPTeX (in blue) and CLASI (in red). Unlike the CAPSER-East, these experiments were limited only to the daytime observations. On days with favorable weather, the cruise starts around 0900 PSD (Pacific Standard Time) from dock at Moss Landing, California and ends at the same location around 1900 PSD. Similar to *Sharp*, the bulk SST measurements from the *Martin* is also from below one meter from the sea surface. *Martin* was fitted with a different radiometer than *Sharp*, known as Remote Ocean Surface Radiometer (ROSR). However, the operation and specifications of ROSR is similar to ISAR.

3. RESULTS

3.1 East coast

Figure 2a shows the quality controlled bulk SST (blue dots) and skin (red dots) SST data sampled during the entire period of CASPER-East. It can be seen that the bulk SST was higher than skin SST most of the time during CASPER-East. This indicates the cool skin effect was the dominant factor determining the ΔSST. Bulk-skin SST difference varied from -0.46°C to 1.24°C during CASPER-East. Approximately 73% of ΔSST were between 0.1°C and 0.5°C and roughly 23% of ΔSST were greater than 0.5°C. Negative ΔSST constituted only 1.5% of the data. Mean bulk-skin SST difference is 0.37°C with a standard deviation of 0.20°C.

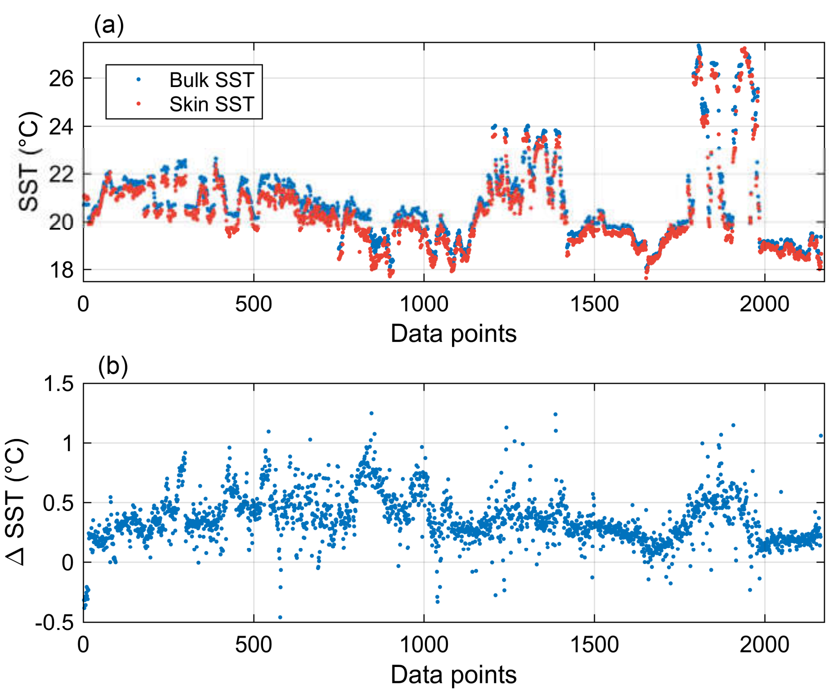

Figure 2: Observed variability of (a) bulk SST and radiometric skin SST and (b) bulk-skin SST difference from CASPER-East measurements.

Figure 3 shows the ΔSST variability with respect to wind speed observed during CASPER-East. Red curve is the average ΔSST for every 2 m s^{-1} wind speed bins. ΔSST shows an increasing trend with decreasing wind speed in the low wind regime. This wind speed dependency of ΔSST is most obvious for wind speeds (< ~ 4 m s^{-1}). However, for moderate and high winds, ΔSST variability is independent of wind speed. Similar bulk-skin

SST difference dependence on wind speed has been reported by previous studies[1, 4]. We also noticed that ΔSST observations corresponding to the low wind (< 4 m s^{-1}) cases also varies diurnally.

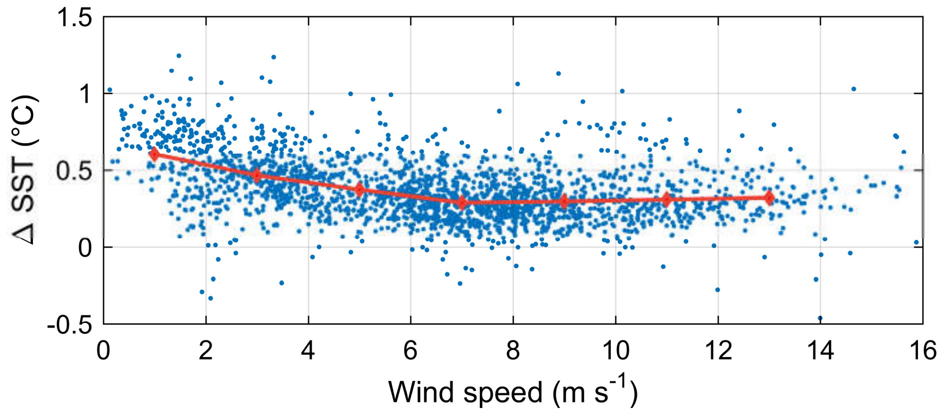

Figure 3: Variability of bulk-skin SST difference with respect to wind speed from CASPER-East measurements.

Figure 4 shows the variability of ΔSST with respect to the local time (Eastern daylight time) of observation. Blue and red curves shows the two hour bin averaged variability ΔSST for low wind (<4 m s^{-1}) and high wind (>4 m s^{-1}) cases. Error bars represent one standard deviation of the data. The diurnal signal is obvious in the blue curve corresponding to low wind cases.it can be seen that higher ΔSSTs found to occur before 0700 EDT and after 1700 EDT. On the other hand, during the daytime, comparatively low ΔSST values were observed under low winds. Diurnal signal was absent in the ΔSST variability corresponding to high wind cases (red curve) nonetheless, a late afternoon (around ~1500 EDT) increase in ΔSST was observed.

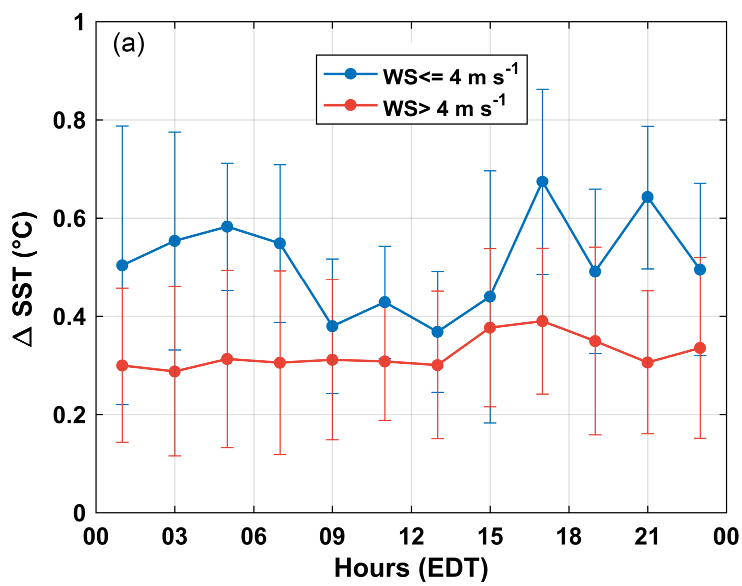

Figure 4: Diurnal variability of bulk-skin SST difference from CEOPTeX and CLASI measurements.

The dependence of bulk-skin SST difference on wind speed and local time of the day is consistent with the role of wind and solar radiation in generating upper ocean mixing and regulating ocean mixed layer temperature.

Wind forcing results in mechanical turbulence in the ocean mixed layer. This mixing effectively reduces the temperature difference at the skin and below the cool skin layer. Solar radiation tends to stabilize the upper ocean and hence reduce mixing. Solar radiation also increases the temperature of all layers of the upper ocean. However, if the amount of shortwave radiation absorbed within the mixed layer is insufficient to overcome cooling from sensible, latent and longwave fluxes, this will result in a reduction in bulk-skin SST difference during the day[12]. Apparently, in the CASPER-East cases, wind speed exceeding 4 ms^{-1} introduced sufficient turbulent mixing to the upper ocean to reduce the solar radiation effect through mixing in a deeper layer. Hence, when winds were relatively strong, the diurnal variation of the bulk-skin SST difference is not apparent. In Figure 5, we show the relationship of downwelling longwave radiation with ΔSST. It shows that higher downwelling longwave radiation leads to lower bulk-skin SST difference. A study of bulk-skin SST difference from Lake Tahoe[13] also reported similar relationship between ΔSST and downwelling longwave radiation. Interestingly, the slope of the linear fit (3.2×10^{-3}) agrees well with the current estimate of 3.0×10^{-3}.

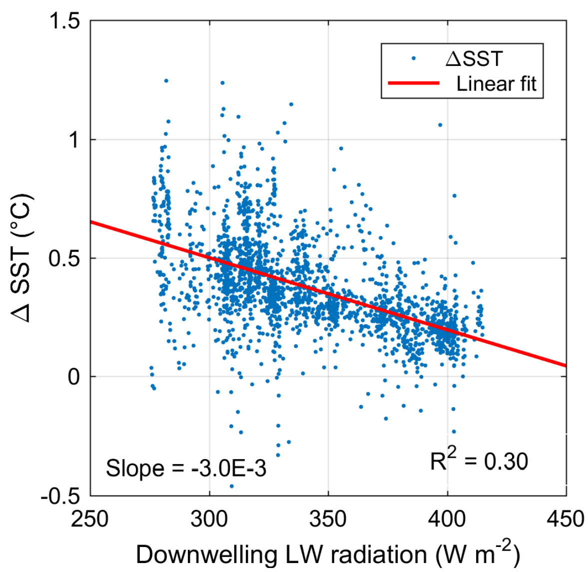

Figure 5: Relationship of downwelling longwave radiation with bulk-skin SST difference.

3.2 West coast

Figure 6 is the bulk (blue) and skin SST (red) observations from the two field experiments conducted at west coast. Bulk and skin SST showed random variability in the Monterey Bay region. Range of variability of ΔSST was from ~-2.3 to ~2.3°C with a mean of 0.1°C. ΔSST was positive for 54% of the observations and rest (46%) of the observations were negative. Standard deviation was around 0.9°C, indicating large variability of ΔSST. It can be seen that ΔSST observations from the Monterey bay showed large swings in comparison with the CASPER-East observations (Figure 2b).

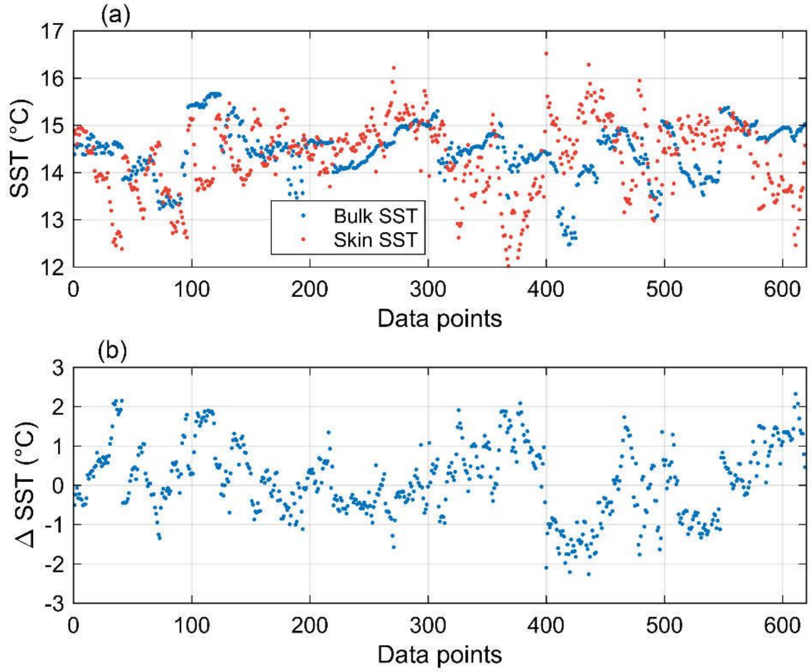

Figure 6: Observed variability of (a) bulk SST and radiometric skin SST and (b) bulk-skin SST difference from CEOPTeX and CLASI measurements.

In Figure 7, we show the ΔSST variability with respect to the wind speed. Unlike the west coast, ΔSST observations from east coast was independent of wind speed. Figure 8 is the ΔSST variability with respect to the local time (Pacific Daylight Time) of observation. Similar to Figure 4, blue and red curves represents the ΔSST corresponding to low wind (< 4 m s^{-1}) and high wind (>4 m s^{-1}) cases. Since the data were limited to the daytime measurements, it is impossible to get a complete picture of diurnal variability of ΔSST using this dataset. However, the ΔSST corresponding to low wind and high wind cases are comparable during the daytime. It is worth mentioning here that the ΔSST variability observed at the Monterey Bay is independent of wind speed. Throughout the spring and summer (March to July) the SST at Monterey bay is governed by the strong upwelling (Ramp et al 2005). Hence, the role of this upwelling cannot be ruled out for the pattern of ΔSST variability observed in the west coast observations. However, more analysis including nighttime observations are required to clarify the ΔSST variability observed in the Monterey bay region.

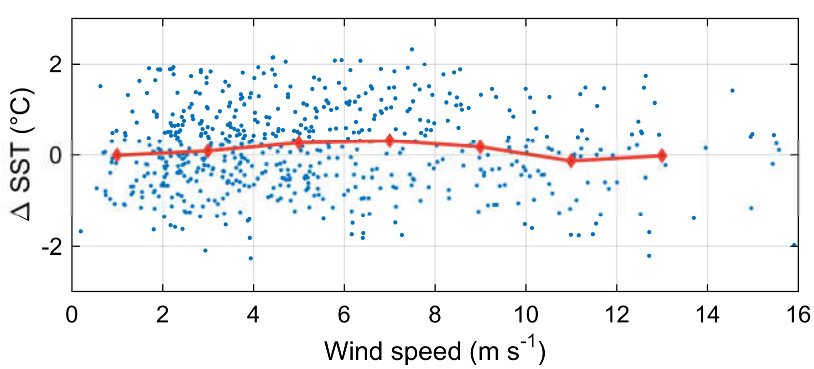

Figure 7: Variability of bulk-skin SST difference with respect to wind speed from CEOPTeX and CLASI measurements.

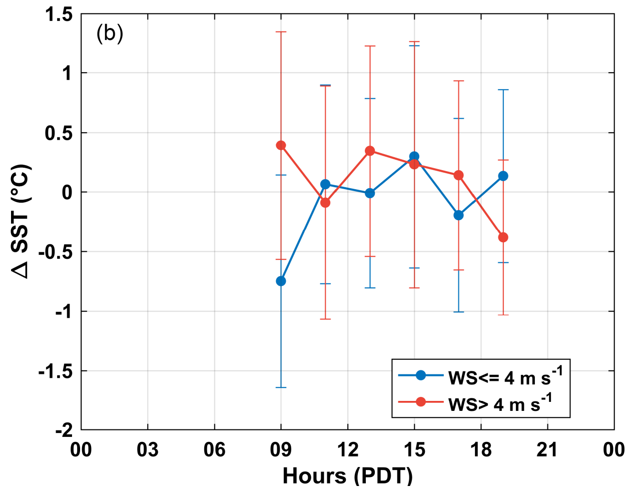

Figure 8: Variability of bulk-skin SST difference with respect to local time of observation from CEOPTeX and CLASI measurements.

4. SUMMARY

Sea surface temperature (SST) is the key parameter required for many oceanographic and atmospheric applications. Air-sea exchange of heat and gases, ocean warming, and cyclogenesis are a few examples of research areas that require accurate SST measurements. Conventionally, the SST measurements are recorded from a few meters below the sea surface using the research platforms such as vessels and buoys. This temperature is often referred as bulk SST. On the other hand, the temperature sensed by a radiometer from the air-sea interface is the skin SST. Bulk SST can differ from skin SST by few tenths of a degree to *O*(1°C), which is regulated by cool skin and warm layer effects. It is known that skin SST must be used instead of bulk SST in various applications to reduce error in quantifications of atmospheric and oceanographic processes[1, 5]. In this study we provide an analysis of bulk-skin sea surface temperature (SST) difference form the west and east coasts of United States using the data collected from three field experiments conducted at offshore Duck, North Carolina and in the Monterey Bay of the California coastal region. Bulk SST measurements were made using conventional thermistors from a depth of one meter below the sea level and skin SST measurements were made using infrared radiometers. East coast observations showed the bulk-skin SST variability between -0.46°C and 1.24°C. Moreover, most of the time during the experiment the bulk SST was higher than skin SST, indicating the dominance of cool skin effect in determining the ΔSST. An increase in ΔSST is observed for wind speeds less than 4 m s^{-1}, and the ΔSST corresponding to the low wind cases also varied diurnally. In other words, ΔSST corresponding to the low wind cases was higher in the nighttime in comparison with daytime. In addition to this, bulk-skin SST difference was found to decrease with increase in downwelling longwave. ΔSST calculated from the observation in the Monterey bay varied between ~2.3° and ~-2.3°C. This was higher than the variability ΔSST observed at the east coast. Moreover, ΔSST variability observed at the Monterey Bay is independent of wind speed. Monterey bay experiences strong upwelling throughout the spring and summer[14]. Therefore, role of upwelling in modulating the ΔSST cannot be ruled out. However, further analysis including nighttime observations are required to understand the effect of upwelling on ΔSST variability.

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