On the Differences between Daytime and Nighttime Cool Skin Signals under Well Mixed Conditions

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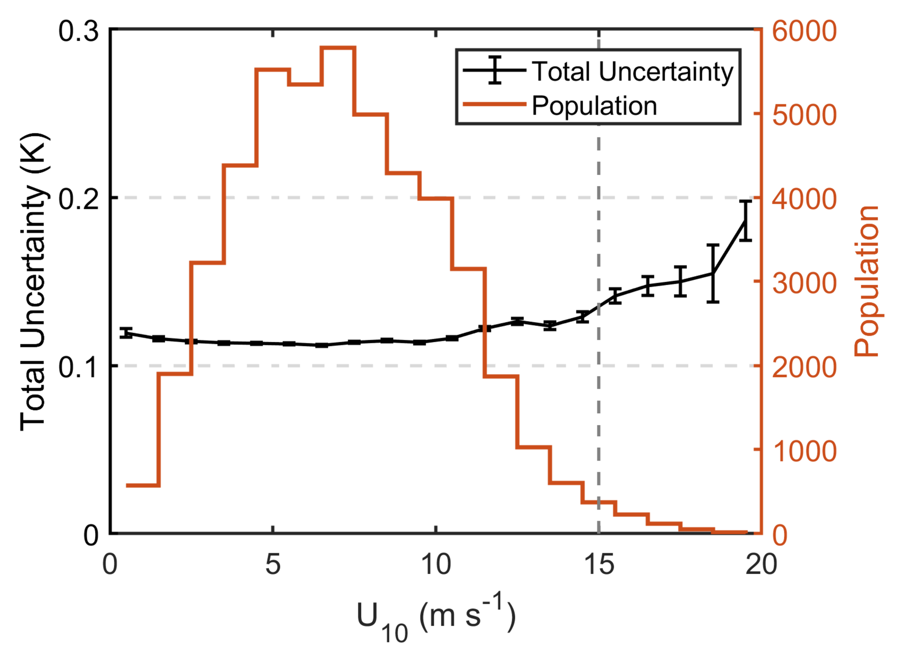
1. Introduction

- Cool skin effect: the skin sea surface temperature (SST_{skin}; measured at 10-20 µm depth by an infrared (IR) sensor) being slightly cooler, typically by a few tenths of a degree, than the subskin temperature ($SST_{subskin}$; measured at ~ 1 mm depth by a microwave (MW) sensor).
- Proper understanding of the cool skin effect is important as it has direct relevance to both air-sea interactions and remote sensing of satellite IR SST_{skin} retrievals.
- Despite our increasingly better understanding of the skin effect over the years, the difference between daytime and nighttime cool skin amplitudes has not received much attention, especially under well mixed conditions.
- This study aims to characterize the differences between daytime and nighttime cool skin signals under well mixed conditions (U_{10} > 6 m s^{-1}) using shipborne IR SST_{skin} and water intake SST_{depth} matchups.

2. Data and Methods

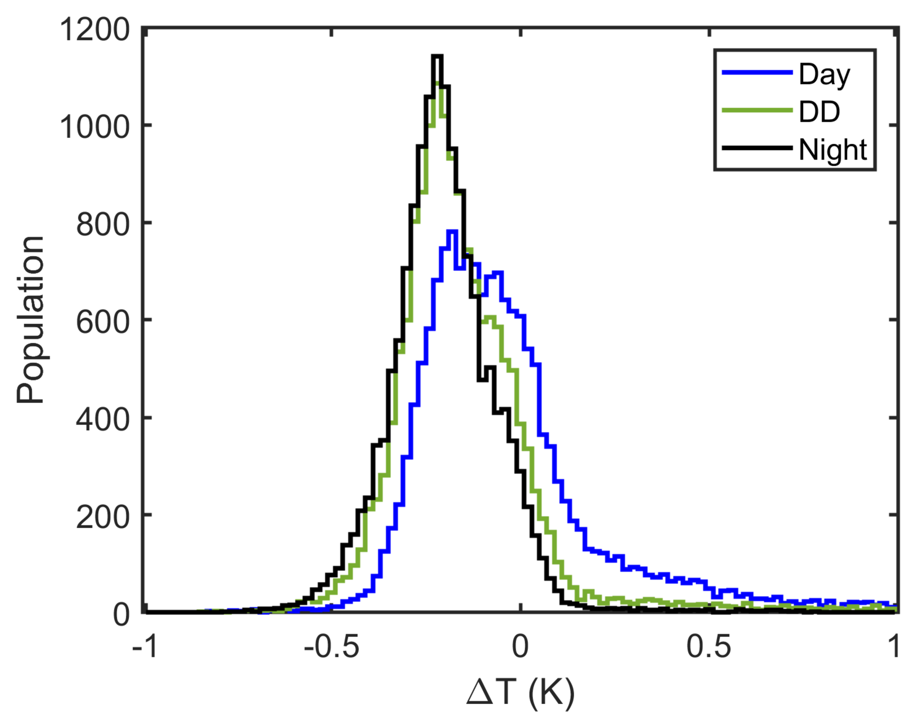
- Skin SST data – measured by the IR SST Autonomous Radiometer (ISAR, model 5D) onboard Australia's Marine National Facility, *R/V Investigator* (> 150 days spanning two years 2016-2017; along Australian coastal transects with a small portion coming from cruises through the Southern Ocean to Antarctica).
- Only SST_{skin} values with total uncertainty <= 0.2 K are adopted (uncertainty code v3.1 based on Wimmer and Robinson, 2016).
- SST_{depth} data – measured by a SeaBird SBE 38 temperature sensor, located within the thermosalinograph water intake in the vessel's drop keel at a depth of approximately 7-10 m below the vessel's summer load line (depending on the position of the drop keel during the voyage), representing $SST_{subskin}$ under mixed conditions.
- Cool skin amplitude is defined as $\Delta T = SST_{skin} - SST_{depth}$.
- Heat fluxes – calculated following the most updated version (v3.6) of the TOGA COARE bulk parameterizations but with ISAR SST_{skin} inputs. Meteorological variable inputs are measured simultaneously with SST on ship.
- The net heat flux, Q_{net}, and the total outgoing heat flux, $Q_{cooling}$, are defined as $Q_{net}=Q_l+Q_s+Q_{lw}+Q_{sw}$ and $Q_{cooling}=Q_l+Q_s+Q_{lw}$, respectively, where Q_{sw} is the shortwave insolation absorbed in the skin layer, Q_{lw} net longwave radiation, Q_l latent heat, and Q_s sensible heat.
- Two cool skin models are adopted: Fairall et al. (1996; hereafter F96) and Wick et al. (2005; hereafter W05).

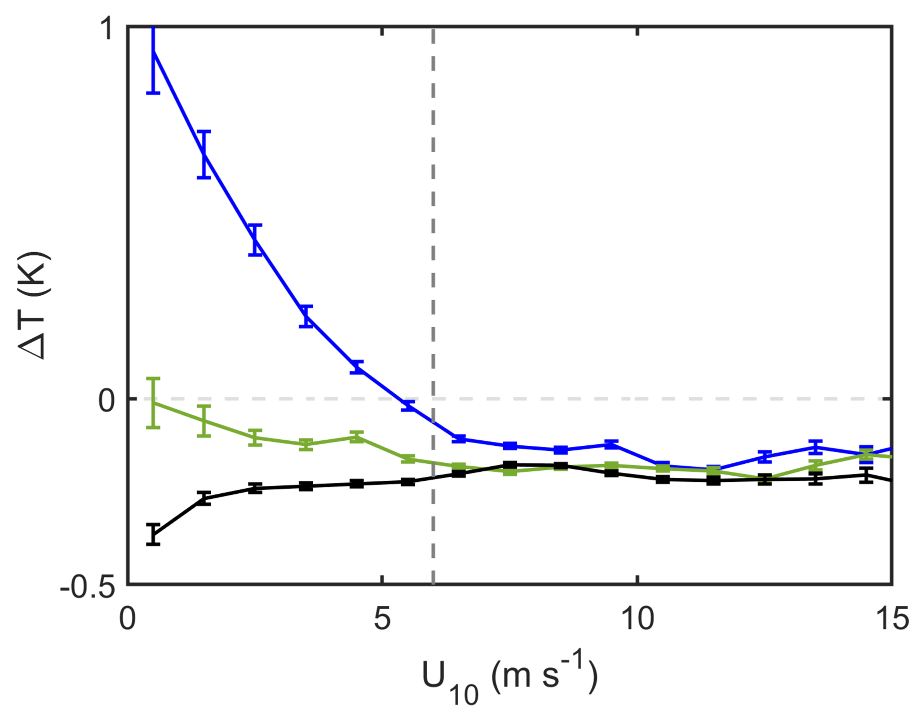
3. Results



The population of SST_{skin} and SST_{depth} collocations and the total uncertainty of ISAR SST_{skin} data as a function of U_{10}. The error bars of the total uncertainty are the 95% confidence level margin of error (MoE), i.e. 1.96 times the standard deviation (SD) divided by the square root of the collocation number. A reference line at U_{10} = 15 m s^{-1} is shown (vertical dash line).

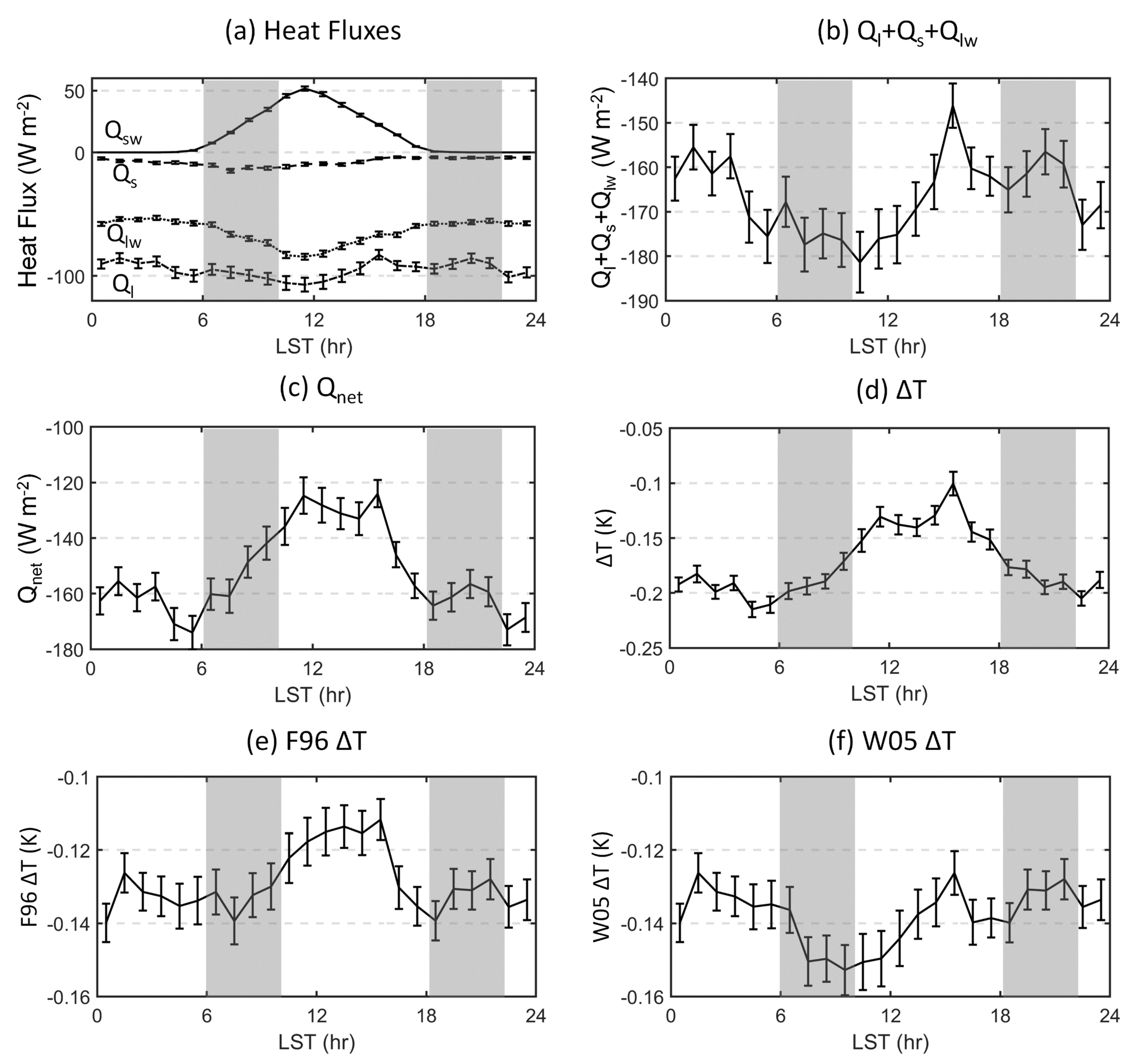
As the total uncertainty increases with U_{10}, in addition to the 0.2 K total uncertainty threshold of SST_{skin}, another filter of 6 < U_{10} <= 15 m s^{-1} is applied to retain the highest possible data quality and the most statistically robust results.





(Upper) The distribution of the mean cool skin values, ΔTs, in daytime (10-18 local solar time, LST; blue), dawn and dusk times DD (Dawn (6-10 LST) and Dusk (18-22 LST); green), and nighttime (22-6 LST; black); and (lower) dependencies of ΔTs on U_{10} for all three periods.

It is interestingly noticed that when U_{10} > 6 m s^{-1} (i.e., the upper few meters considered well mixed and the diurnal warming effect minimised), the ΔTs for all three periods tend to reach *different* asymptotic values. The daytime ΔTs are consistently closer to zero than nighttime.



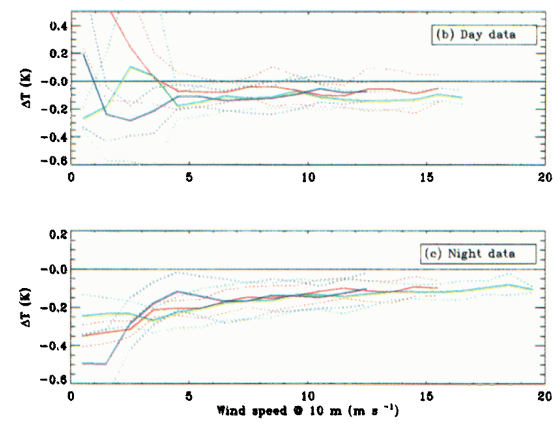
For 6 < U_{10} < 15 m s^{-1}, the diurnal variation of (a) individual heat fluxes; (b) $Q_{cooling}$; (c) Q_{net}; (d) ΔT in this study; (e) F96 ΔT; and (f) W05 ΔT. Note that compared with panel (d), panels (e) and (f) have smaller y-axis ranges to highlight their diurnal ranges. The shaded columns indicate the DD times. Error bars are the 95% confidence level MoE.

Under well mixed conditions, a clear diurnal variation pattern is identified in the measured ΔTs: the smallest (largest) ΔT size of ~ -0.10 K (~ -0.21 K) is found at 15-16 (4-5) hr LST. The ΔT diurnal range reaches ~ 0.11 K. The measured ΔTs are highly correlated with Q_{net}.

The F96 model picks up the ΔT diurnal pattern well, and closely follows that of Q_{net} but strongly underestimates the nighttime ΔT size (by ~ 0.04-0.06 K), hence the diurnal range (by ~ 0.08 K). The W05 model predicts slightly increased amplitudes of daytime ΔTs due to reduced Q_{sw}, which agree better with observations.

4. Discussion

The fact that under well mixed conditions (defined as U_{10} > 6 m s^{-1} in both day and night in this study), the cool skin signal at night may be slightly larger than during the day has been touched on, but not elaborated upon, in several previous papers. Below are a few examples.



Donlon et al. (1999; Fig. 2): day ΔTs are consistently smaller than night in different experiments (colours) when U_{10} is > 6 m s^{-1}.

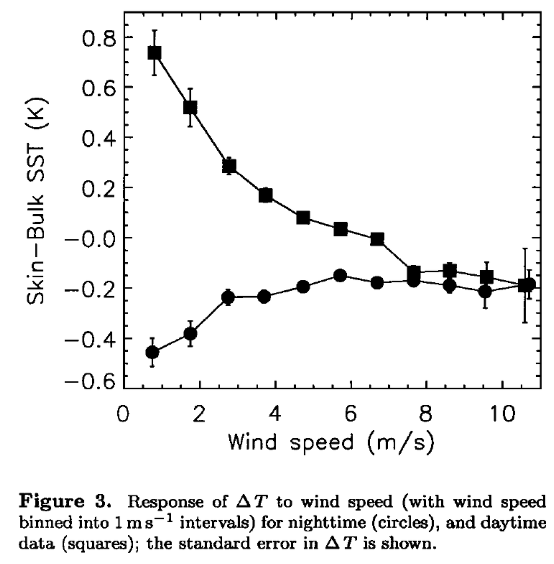


Fig. 3 from Murray et al. (2000)

- In Donlon et al. (2002), their Table 1 shows that four out of six cruises have smaller daytime average ΔT than nighttime by 0.02 to 0.07 K when U_{10} > 6 m s^{-1}, whereas the two other cruises have equal values.
- Wilson et al. (2013) argue that "*Immediately after sunrise the skin effect is at its maximum for the daytime*," in good agreement with our findings in this study.

We believe SST data uncertainties should not significantly affect our results as we are concentrating on relative, instead of absolute, values of these ΔTs, unless the biases in both ISAR and SBE38 sensors are diurnally varying which is not likely. In addition, a relatively large matchup database is used to ensure statistically significant results.

5. Conclusions

- When U_{10} is > 6 m s^{-1}, daytime average ΔT (-0.14 ± 0.13 K) is smaller than at night (-0.20 ± 0.10 K) by ~ 0.06 K. A pronounced diurnal variation pattern in ΔT is observed, with a maximum (minimum) value of ~ -0.21 K (~ -0.10 K) found at 4-5 hr (15-16 hr) LST, highly correlating with Q_{net} (following Fairall et al. 1996).
- The Q_{sw} calculated from Fairall et al. (1996) proves to be a critical driver in the ΔT diurnal evolution.
- Both F96 and W05 cool skin models (the latter simply employing a reduced daytime Q_{sw}) can pick up the ΔT diurnal pattern to a certain degree, but with much smaller ranges. On average, F96 underestimates nighttime ΔTs by 0.04-0.06 K, hence the diurnal range by ~ 0.08 K.
- In terms of application, we recommend that different constants should be subtracted from in situ measurements for day (-0.14 K) and night (-0.20 K) when calibrating or validating satellite SST_{skin} data under well mixed conditions.

References

1) Donlon et al. (1999), *Geophys. Res. Lett.*, 26(16), 2505-2508.
2) Donlon et al. (2002), *J. Clim.*, 15(4), 353-369.
3) Fairall et al. (1996), *J. Geophys. Res. Oceans*, 101(C1), 1295-1308.
4) Murray et al. (2000), *Geophys. Res. Lett.*, 27(8), 1171-1174.
5) Wick et al. (1996), *J. Phys. Ocean.*, 26(10), 1969-1988.
6) Wilson et al. (2013), *J. Geophys. Res. Atmos.*, 118(18), 10,332-10,346.
7) Wimmer and Robinson (2016), *J. Atmospheric Ocean. Technol.*, 33(11), 2415-2433.

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