Final Report

Wake verification and validation study

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MAJOR GOALS

We propose an experimental procedure to measure and characterize the remotely sensed wake signature and the in situ relevant parameters of wakes left from passing ships and disturbances in open bodies of water. As is shown in observations from airborne and satellite sensors, a shallow (meters), frequently occurring warm surface layer and a cool skin in the ocean are often disrupted and mixed by a passing vessel and this wake is observable through remote sensing until it is dissipated (minutes to hours). The strength and evolution of the wake parameters (temperature contrast, roughness, width, turbulence) will depend on the specifics of the vessel (speed, size) and the ambient surface conditions (thermocline, heat flux, waves, wind). Over time, these signatures will be horizontally smeared by ocean currents, stirring, and restratification processes, and vertically dispersed due to vertical mixing, shear, and bubble rise and dissolution processes. All these processes depend on the winds, waves, and sea state. Thus, the observations will need to provide measurements of the wake evolution and ambient parameters over the period from the wake genesis to its destruction. These include:

1. EO and thermal IR surface imagery
2. ambient turbulence, wave, and surface roughness conditions
3. ambient surface temperature and salinity profiles
4. meteorology including net air-water heat flux
5. time series of the in-wake turbulence, temperature and mixing profiles
6. in-wake waves and surface roughness proxies
7. Surface currents (which can advect signals and/or alter wave propagation)

The main goal will be to provide initial validation data for the TWakes model, a thermal mixing and renewal model, developed by Less, Chickadel, and Reinhardt [2017, ONR final report].

APPROACH

Our methodology was focused on large scale remote sensing using thermal infrared (IR), visible band (EO) together with in situ sampling of the surface warm layer. All of the remote sensing instruments are combined in the Compact Airborne System for Imaging the Environment (CASIE) and flown onboard a Cessna 182 light aircraft. In situ measurements were made via SWIFT drifters which included ocean temperature, turbulence, and air side meteorology data. We surveyed the region in Dabob Bay in Hood Canal, WA, over four days. SWIFT drifters [*Thomson*, 2021] were deployed simultaneously using a small boat.

ACCOMPLISHED

We have used our data to test the COARE algorithm [*Fairall et al.*, 2003], a well-known and widely used diurnal warm layer and skin-temperature model. In review, the remotely sensed and in situ data we collected of near surface and surface ocean conditions and meteorology data (temperature, waves, wind, skin temperature) in 2019 spanned times from near dawn to dusk to capture the daylight development and evolution of the diurnal warm layer. Conditions were mostly sunny and winds varied from 0 to 5 m/s, which caused light white capping. Of note, the wind mixing increased throughout the time period as indicated in the observed mixing and the resulting temperature profiles. Skin brightness-temperature was observed from a long-wave (9- 13 microns) radiometer down-looking on plane. The corrected skin temperature was calculated using a constant sky temperature of -30 C, consistent with a clear sky. Figure 1 shows the measured in situ near surface temperature (down to 1.2 m depth) and radiometrically measured skin temperature. We note that the near surface layer can have dynamic temperature ranges, here spanning up to almost 4 C under calm sunny conditions where solar heating and low mixing allow a strong diurnal warm layer to develop. The skin temperature, as expected closely follows the nearest surface, 0.2m depth, temperature. The subskin-skin temperature difference, ΔT, varies over the experiment from -0.5 C (warm skin) to 1.5 C (cool skin).

The COARE algorithm is flexible in that it will take input of a minimal set of data for use in calculating the surface warming and skin-layer temperature. Here, we have used input measurements from the SWIFT drifters including of air and subsurface-water temperature and wind speed. Observations of short-wave radiation were used form a nearby land-based meteorology station. A model of downwelling long-wave radiation was used to initiate the model. The COARE calculated skin temperature, heat flux components, and 10-m wind speed are shown in Figure 2. The COARE modeled ΔT is plotted in Figure 1. We found general agreement with the observed skin temperature, though there was significantly more scatter in the observations than the model (Figure 3), and we see that the COARE estimated ΔT has a close dependence on the wind speed, similar to DT estimated from a model by *Minnett et al*. [2012]. Interestingly the data show a possible proportional dependence on wind speed, contrary to both models, which are inversely proportional to wind speed. Mitigating conditions which could contribute to this are the effects of the wind sheltered location of the measurements in Hood Canal and sources of freshwater that contribute to lateral heat advection, which would violate the basic assumptions of the models and complicate the cool skin estimates since the in situ measurements were concentrate within a 0.5 km region of the study site and plane observations sampled several km of the site.

IMPACT/IMPLICATIONS

Our research has added examples of the complexity of the sea surface temeprature. This data set will continue to be analyzed and used for model development and validation of diurnal warm-layer predition and skin temperature modeling.

TECHNOLOGY TRANSFER AND RELATED PROJECTS

Data from the airborne system and drifters have been delivered to NIWC for further analysis and compilation. We are currently assisting NIWC with data interpretation and analysis. We are also collaborating with NRL and ThermoAnalytics Inc. (DoD contractor) on similar analysis. Experience and findings from this research will be shared with the NUWC UPSIDE program.

REFERENCES

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Minnett, P. J., Smith, M., & Ward, B. (2011). Measurements of the oceanic thermal skin effect. *Deep Sea Research Part II: Topical Studies in Oceanography*, *58*(6), 861-868.

Thomson, J. (2012) Wave breaking dissipation observed with 'SWIFT' drifters, *Journal of Atmospheric and Oceanic Technology, 29,* doi:/10.1175/JTECH-D-12-00018.1.

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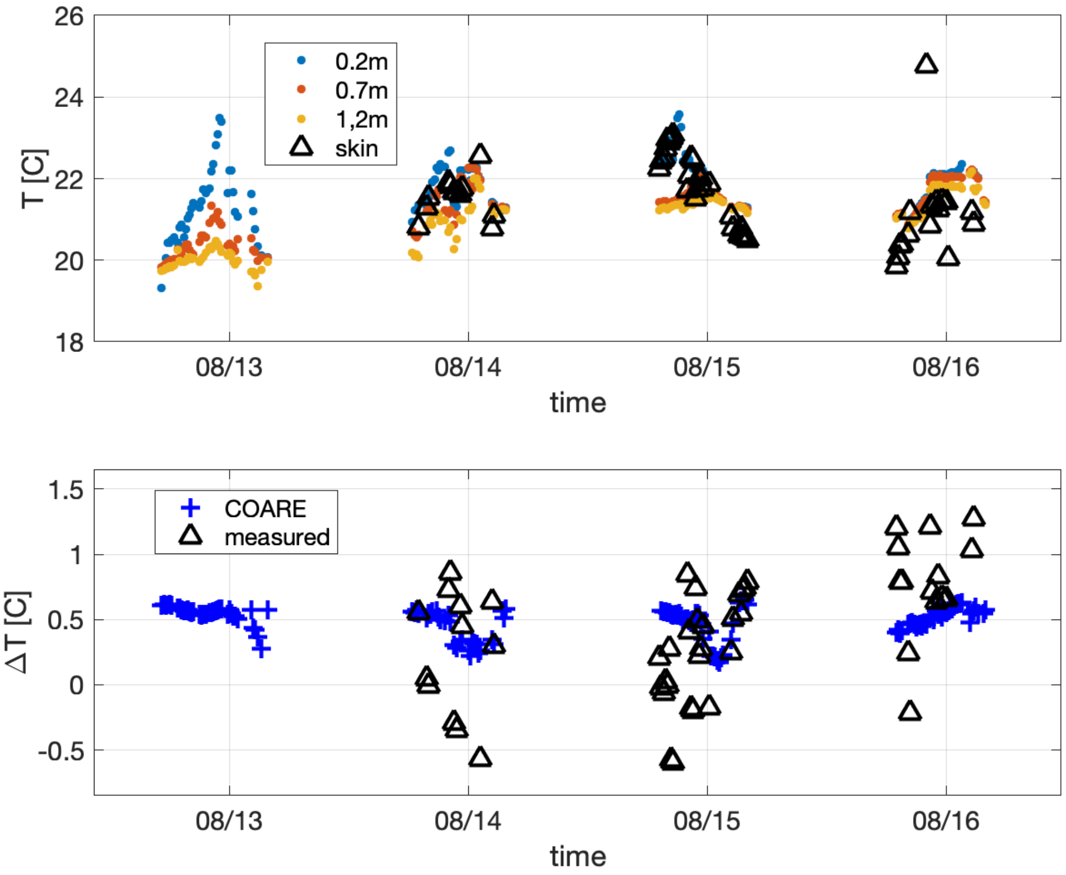

Figure 1. *(top) Times series of in situ ambient temperature data of the near surface (1.2m to 0.2m depth) and radiometrically measured skin temperature. (bottom) The measured subskin-skin temperature difference is shown with the COARE-modeled subskin-skin temperature difference.*

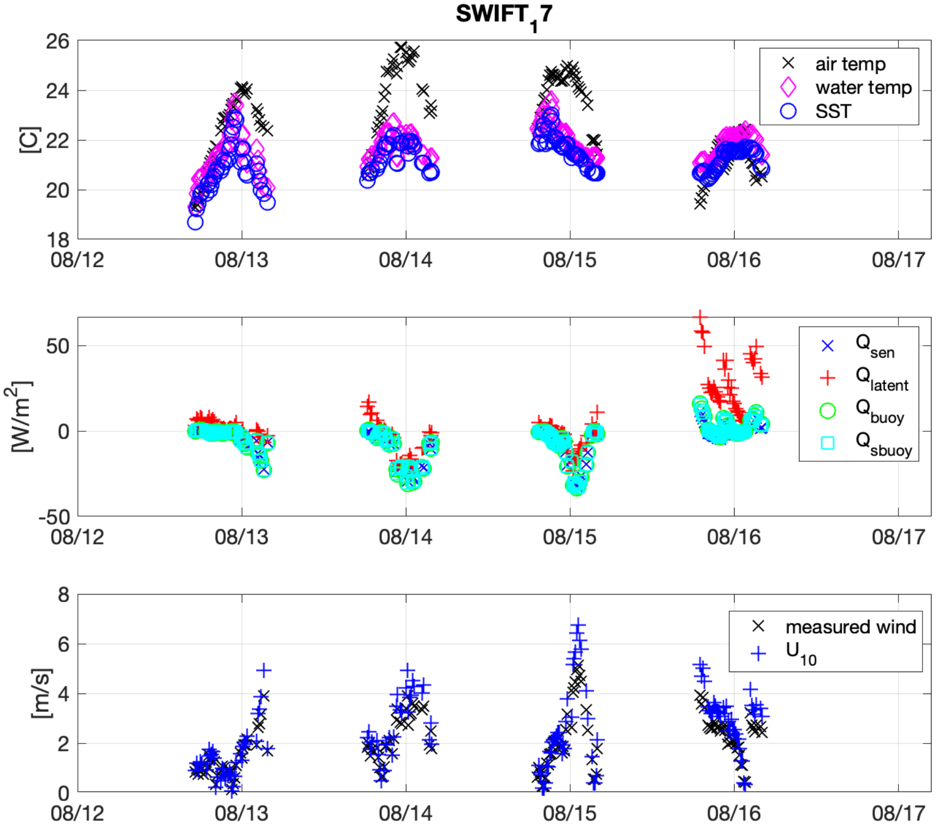

Figure 2. *(top) measured air and water temperature and COARE calculated skin temperature. (middle) COARE estimated net sensible, latent and heat flux and two estimates of the air-side thermal buoyancy flux. (bottom) Measured and 10-m estimated wind speed.*

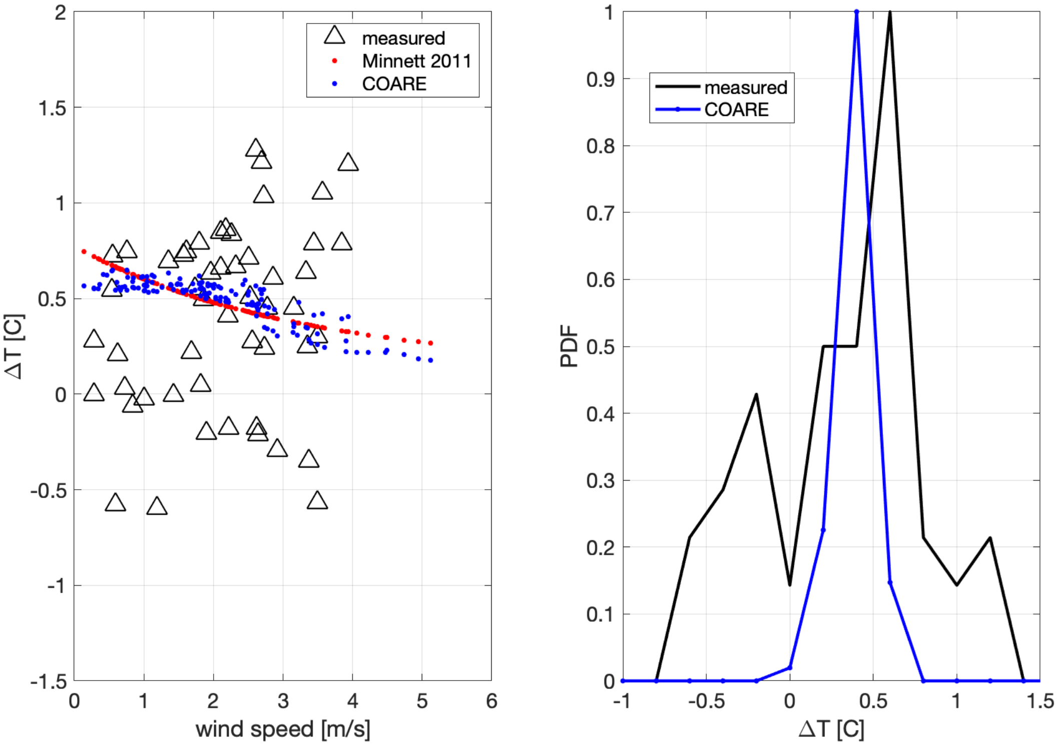

Figure 3. *(left) wind speed plotted against measured and modeled ΔT. (right) the distribution of the measured and modeled (COARE) ΔT.*

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14. ABSTRACT

We propose an experimental procedure to measure and characterize the remotely sensed wake signature and the in situ relevant parameters of wakes left from passing ships and disturbances in open bodies of water. The main goal will be to provide initial validation data for a thermal mixing and renewal model, developed by Less, Chickadel, and Reinhardt [2017, ONR final report]. Our methodology was focused on large scale remote sensing using thermal infrared (IR), visible band (EO) together with in situ sampling of the surface warm layer. All of the remote sensing instruments are combined in the Compact Airborne System for Imaging the Environment (CASIE) and flown onboard a Cessna 182 light aircraft. In situ measurements were made via SWIFT drifters which included ocean temperature, turbulence, and air side meteorology data. We successfully collected four days of data in Dabob Bay within Hood Canal WA. These data were processed and delivered to our partner at NIWC for further analysis. We have also used our data to test the COARE algorithm, a well-known and widely used diurnal warm layer and skin-temperature model which showed moderate agreement. This data set will continue to be analyzed and used for model development and validation of diurnal warm-layer prediction and skin temperature modeling.

15. SUBJECT TERMS

Thermal remote sensing, sea surface temperature, diurnal warm layer

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