The Response of the Ocean Thermal Skin Layer To Air-Sea Interfacial Heat Fluxes

UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of MARINE & ATMOSPHERIC SCIENCE

Elizabeth W. Wong[1] & Peter J. Minnett[2],

(1) Meteorology and Physical Oceanography Program, University of Miami, 4600 Rickenbacker Causeway, Miami, FL, 33149-1031, USA, Email: ewong@rsmas.miami.edu

(2) Department of Ocean Sciences, University of Miami,4600 Rickenbacker Causeway, Miami, FL, 33149-1031, Email: pminnett@rsmas.miami.edu

Introduction

- This study aims to answer the conundrum of the mechanism as to how absorption of incident longwave (LW) radiation causes an increase in upper ocean heat content (OHC) (0-700 m) when the penetration depth of LW extends only to micrometer scales (Fig. 1).
- We hypothesize the temperature profile in the thermal skin layer (TSL) is responsive to changes in the incident infrared radiation, thus modulating the heat derived from the absorption of sunlight that is retained in the upper few meters of the ocean.

Methods and Data

- The TSL vertical temperature profile is retrieved from sea surface emission spectra obtained from an infrared (IR) spectrometer called the Marine-Atmospheric Emitted Radiance Interferometer (M-AERI) (Fig. 2). Retrievals are performed utilizing properties of the electromagnetic (EM) skin layer (Fig. 1) and the Truncated Singular Value Decomposition technique (Wong & Minnett, 2016a, b).

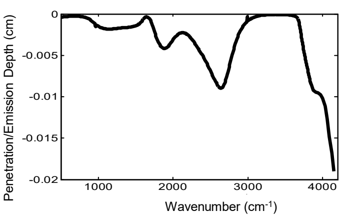


Fig 1. Plot of penetration depth with wavenumber (Bertie and Lan, 1996).

Fig 2. M-AERI on the AMMA06 cruise. Photograph taken by Dr Erica Key.

- Effects of solar radiation, precipitation and high winds of > 10 ms^{-1} are filtered out such that the focus is on the effects of the TSL and longwave radiative fluxes.

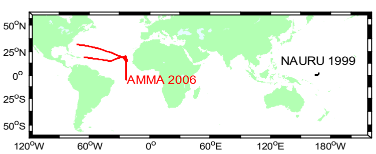
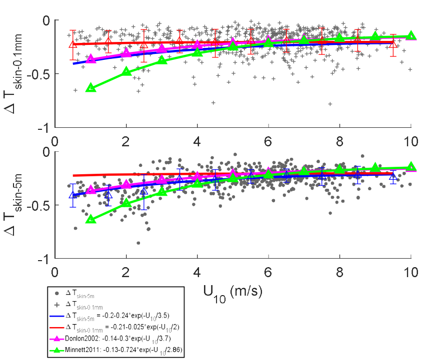


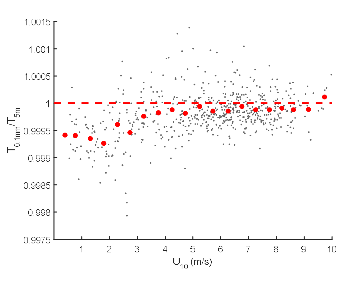
Fig 3. Black: Cruise tracks of the Nauru 1999 expedition (black) on the R/V *Mirai*, June to July 1999.
Red: Cruise tracks of the African Monsoon Multidisciplinary Analysis 2006 (AMMA 2006) campaign on the NOAAS *Ronald H Brown*, May to June 2006.

- Radiation from cloud forcing is used as a surrogate for greenhouse gas forcing. This provides a stronger longwave signal in short time intervals thereby allowing the problem to be tractable.

Results – wind dependences

- Evidence of a thicker TSL at low winds

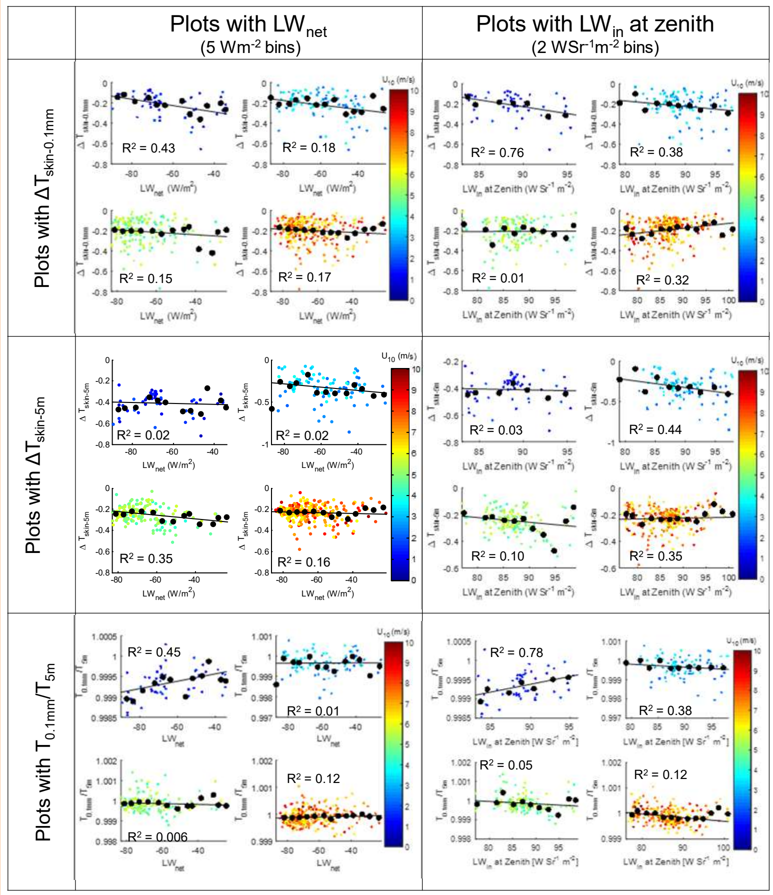




- At low winds (U_{10}< 4 ms^{-1}), thickness of TSL exceeds EM skin layer depths, resulting in the retrieval of the deepest temperature to not be representative of the temperature of the bottom boundary of the TSL.
- At higher winds (U_{10}> 4 ms^{-1}), wind driven shear stresses have thinned the TSL, resulting in the retrieved subskin temperature approaching the 5 m temperature, which is within the isothermal mixed layer.

Results – Flux Dependences

- Evidence of change in the vertical structure of TSL under low winds



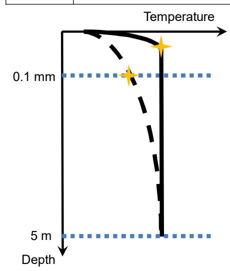


Fig 4. Cartoon of TSL profile under low winds. Solid black line represents TSL profile at high LW_{in}. Dotted black line represents TSL profile with low LW_{in}. Yellow star denotes retrieved "subskin" temperature, $T_{0.1mm}$.

- $\Delta T_{skin\text{-}5m}$ is independent of longwave radiation.
- At U_{10} < 2 ms^{-1}, significant correlation between LW_{in} with $\Delta T_{skin\text{-}0.1mm}$ and $T_{0.1mm}/T_{5m}$ shows that as cloud closes the atmospheric window (higher LW_{in} values), the TSL profile varies from the dashed black curve to the solid black curve in Fig. 4.
- Similar relationship observed with a decrease in upward LW_{net} at U_{10} < 2 ms^{-1}, showing a transition to a steeper but thinner TSL (solid black curve in Fig. 4).
- This implies that under the absence of wind forcing, the ocean's response to increasing LW radiation is due to changes in the internal structure of the TSL profile rather than variations of the temperature difference across the TSL.

Conclusion

Analysis indicates evidence that an increase in LW_{in} varies the curvature of the TSL such that the TSL has a higher temperature gradient near the interface and a lower temperature gradient at subskin depths. This implies that at lower LW_{in}, the TSL permits the effective removal of heat from the mixed layer to the atmosphere whereas the curvature change due to an increase in LW_{in} hinders the release of heat from the mixed layer and is instead effective in releasing heat within the TSL. This results in the retention of solar radiation, increasing the upper ocean heat content.

References

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