Significant Diurnal Warming Events and Ocean Warm Skin Signals Observed by Saildrone at High Latitudes

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CONTENT

Find further details from:

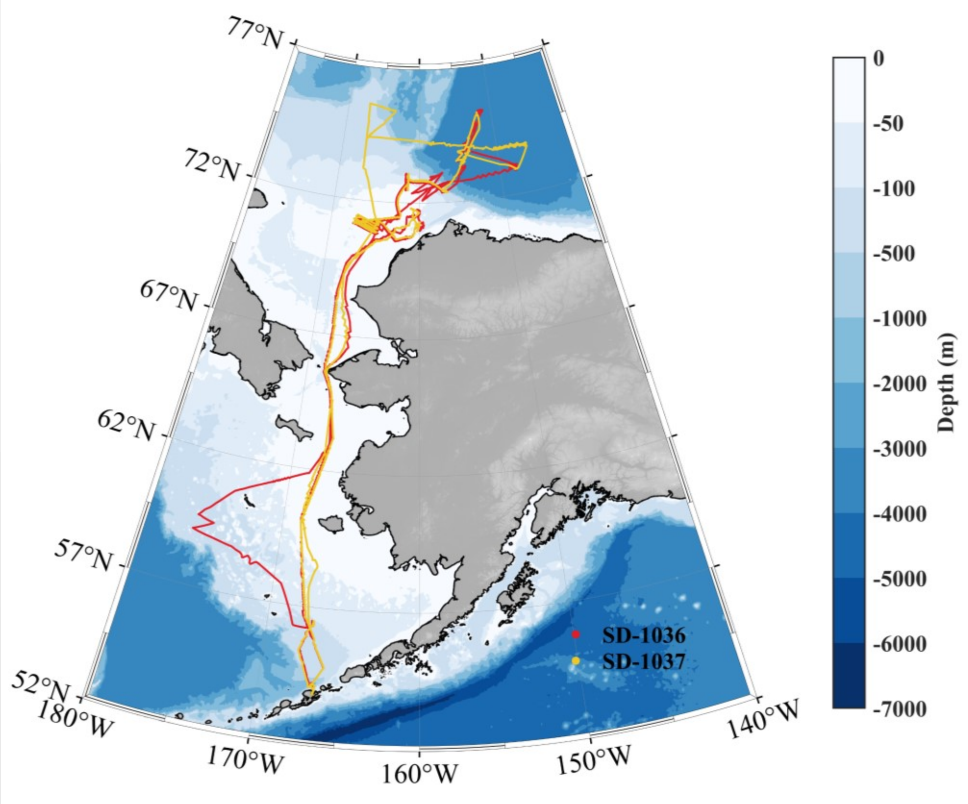
Jia, C., Minnett, P. J., & Luo, B. (2023). Significant diurnal warming events observed by Saildrone at high latitudes. *Journal of Geophysical Research: Oceans*, 128, e2022JC019368. https://doi.org/10.1029/2022JC019368

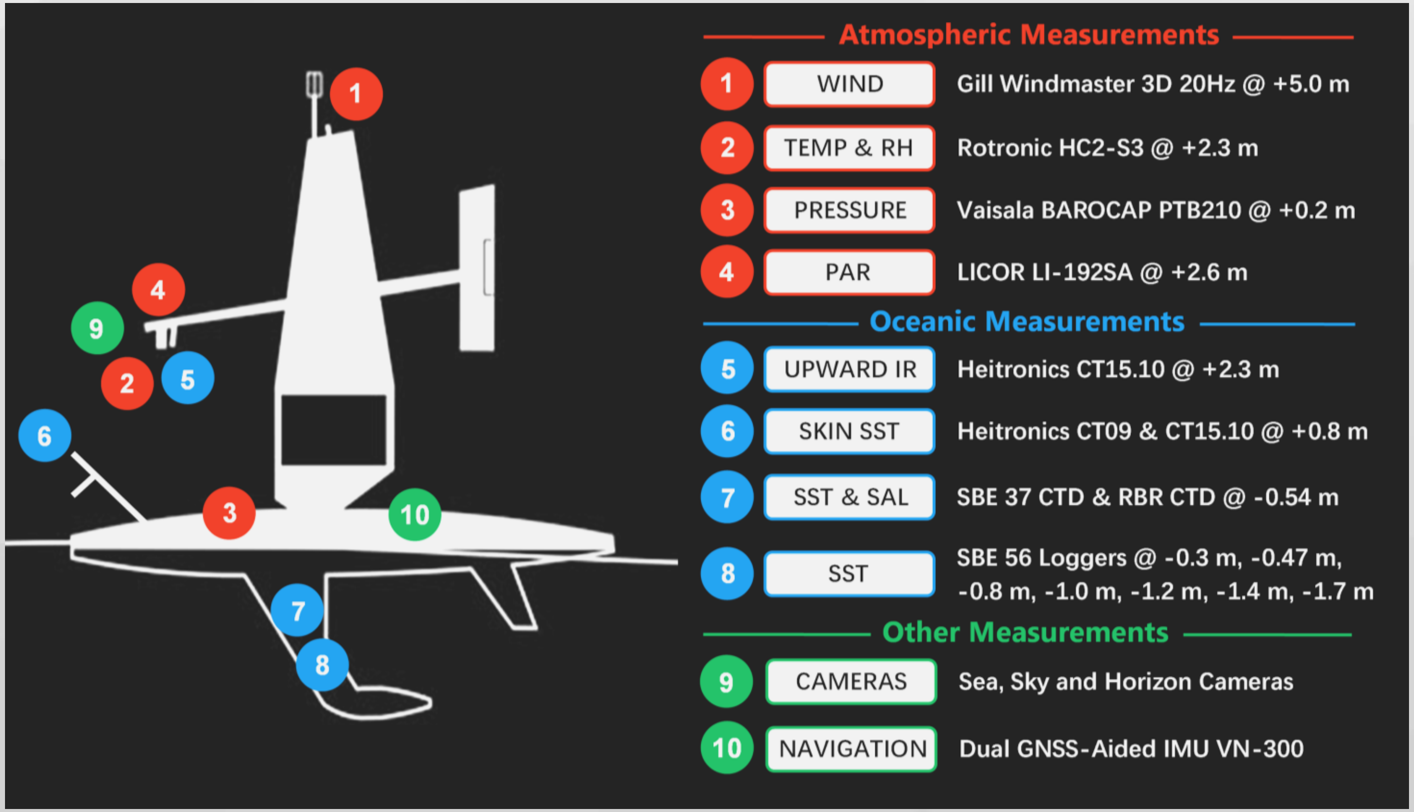
Jia, C., & Minnett, P. J. (2023). Ocean warm skin signals observed by Saildrone at high latitudes. *Geophysical Research Letters*, 50, e2022GL102384. https://doi.org/10.1029/2022GL102384

1 Introduction

Research Background

2019 Saildrone Arctic Cruise





- Two Saildrones, SD-1036 and SD-1037, funded by NASA through the National Oceanographic Partnership Program (NOPP), undertook a 150-day cruise, departing from Dutch Harbor, Alaska, from 15 May to 11 October 2019.
- The Saildrone is a wind-driven autonomous surface vehicle (ASV) manufactured by Saildrone, Inc., collecting high-resolution data with a suite of onboard solar-powered oceanographic and meteorological sensors.

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Data

Research Methodology

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SST & Other Auxiliary Datasets

- **SST Data from Saildrone**
  - Skin SST (SST_{skin}) retrieved from the measurements taken by SD-1036 and SD-1037, which are proven to be sufficiently accurate (~0.12 K) for scientific research after rigorous quality control. Please see:

C. Jia, P. J. Minnett, M. Szczodrak and M. Izaguirre, "High Latitude Sea Surface Skin Temperatures Derived From Saildrone Infrared Measurements," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 61, pp. 1-14, 2023, Art no. 4200214, doi: 10.1109/TGRS.2022.3231519.

  - Subsurface SST (SST_{depth}) taken by several instruments carried by Saildrones, including two CTDs that both measure temperature at -0.54 m depth, and seven temperature loggers installed along the keel from -0.3 to -1.7 m depth.

- **Meteorological Variables from Saildrone**
  - Wind speed (U) at 5 m
  - Air temperature (T_{air}) and relative humidity (RH) at 2.3 m
  - Barometric pressure (P) at 0.2 m
  - Photosynthetically Active Radiation (PAR) at 2.6 m

- **Downward longwave radiation from ERA5**

Formulae for Calculation

$$SST_{skin} = SST_{depth}(z) + \Delta T_c + \Delta T_w(z)$$

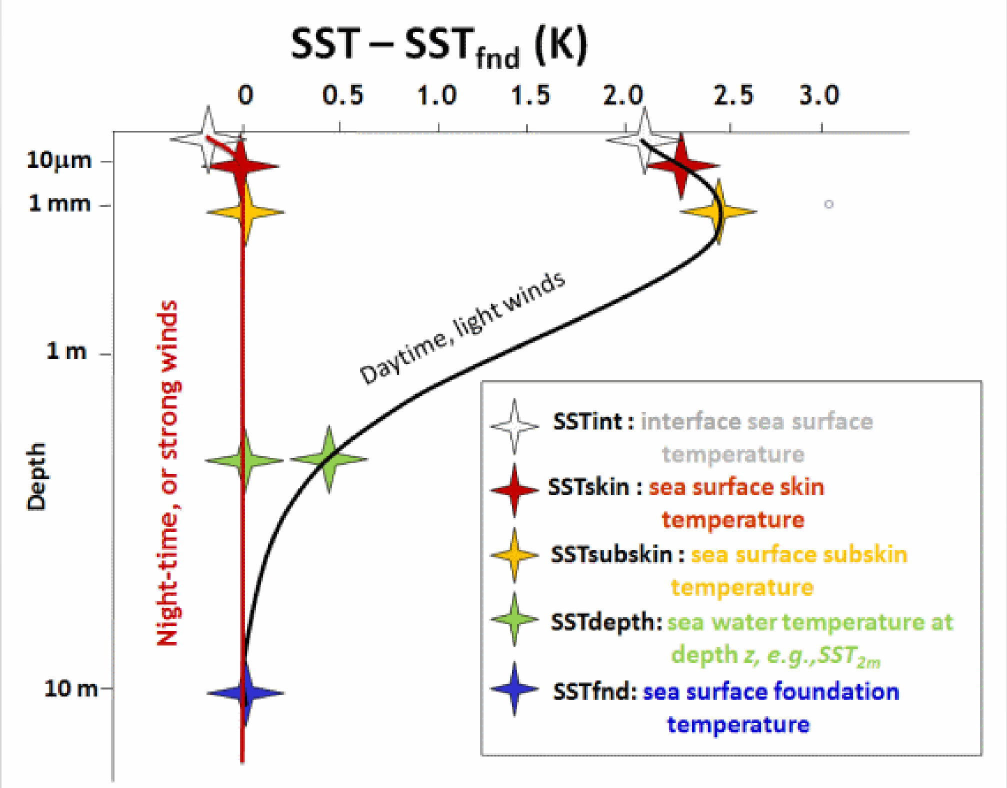
$$Q_{net} = f_c SW_{net} + Q_c$$

$$Q_c = Q_{sen} + Q_{lat} + LW_{net}$$

$$SW_{net} = SW \downarrow (1 - \alpha)$$

$$SW \downarrow = PAR/2.4$$

$$LW_{net} = LW \downarrow - LW \uparrow = \varepsilon\left(LW \downarrow - \sigma {T_s}^4\right)$$

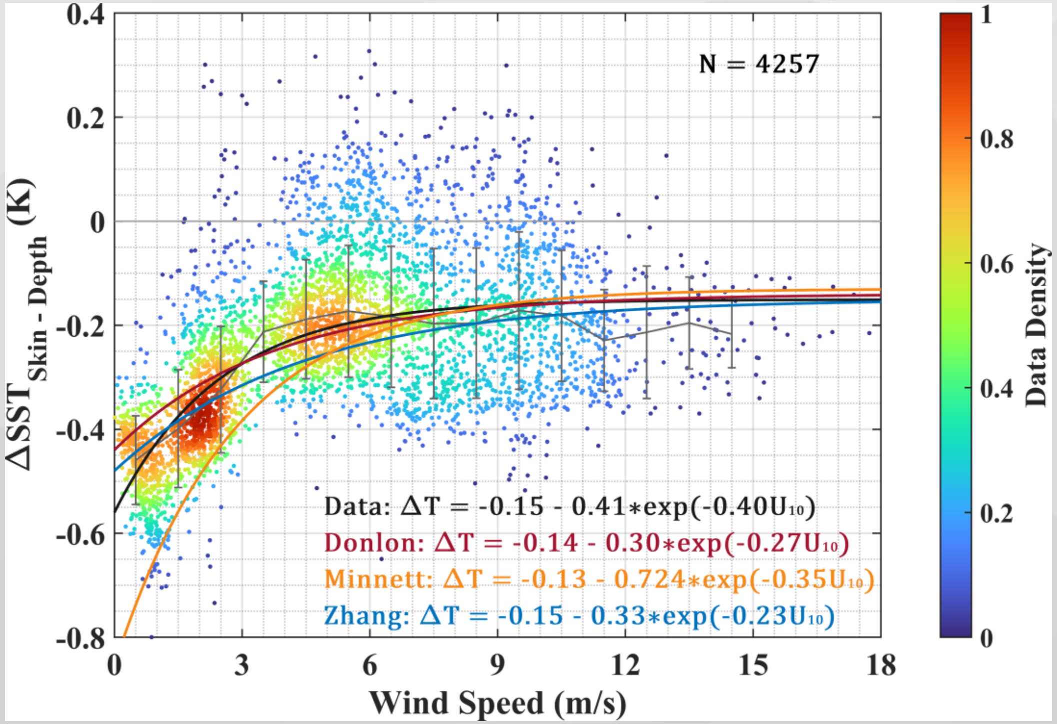


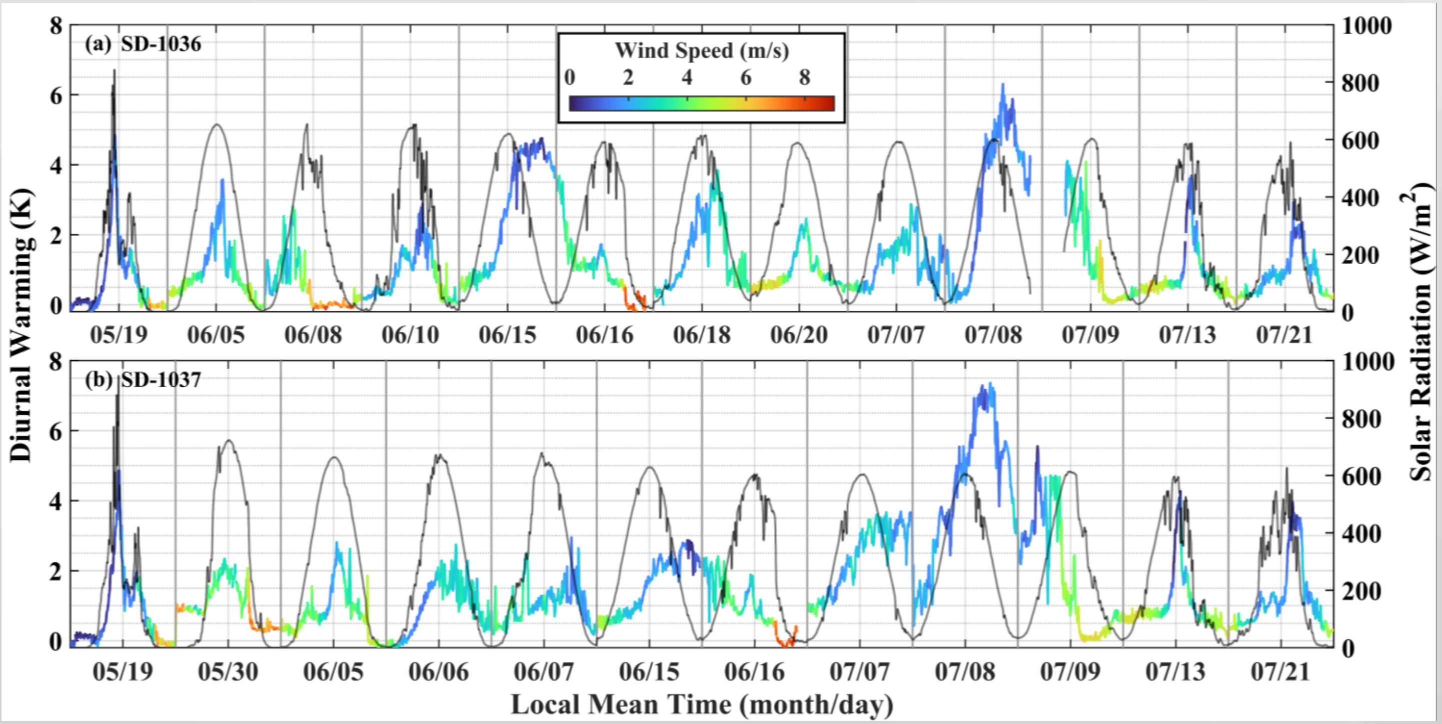
- ΔT_c: Cool skin effect
- $\Delta T_w(z)$: Diurnal warming if present in the depth z of the ocean
- Q_{net}: Net heat flux within the thermal skin layer
- Q_c: Heat loss/gain through the thermal skin layer
- SW_{net}: Net shortwave radiation
- LW_{net}: Net longwave radiation

3 Results

Research Procedure

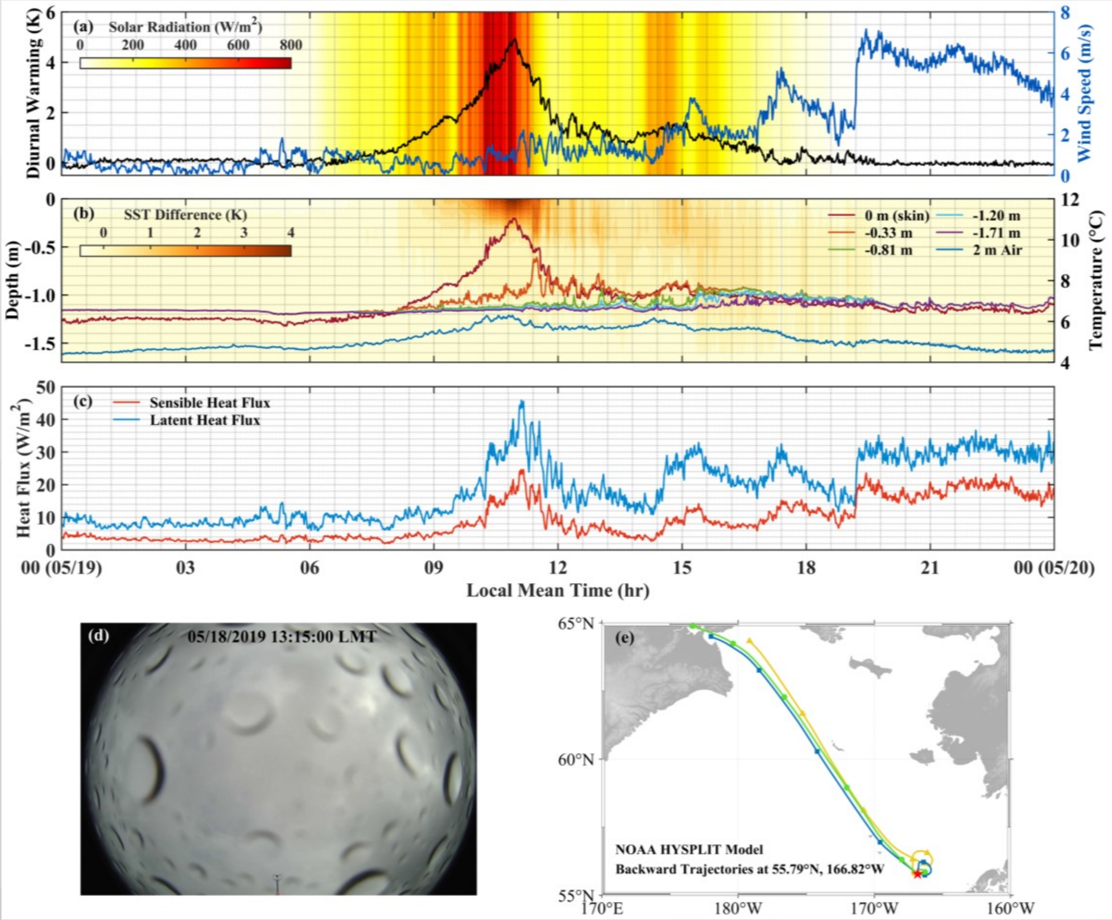
Cool Skin Parameterization & Large Diurnal Warming Events

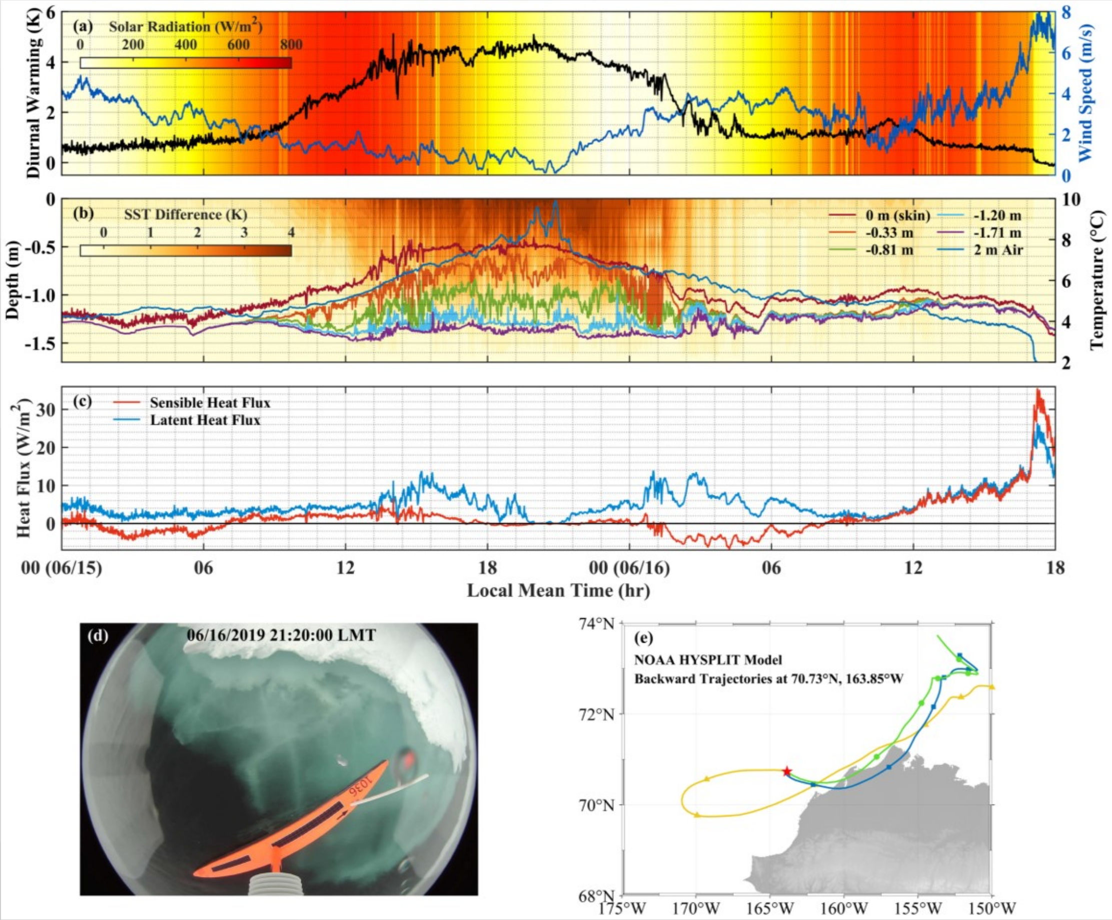




- Large warming events result from strong insolation and little near-surface mixing due to low wind speeds.
- The highest temperature of a day usually did not occur at the time of the strongest insolation, but with a lead or delay depending on wind speed.
- Some diurnal warming persisted from one day into the next, e.g., on 15-16th June and 7-9th July due to the midnight sun in the Arctic.

Specific Diurnal Warming Events (05/19 & 06/15-06/16)

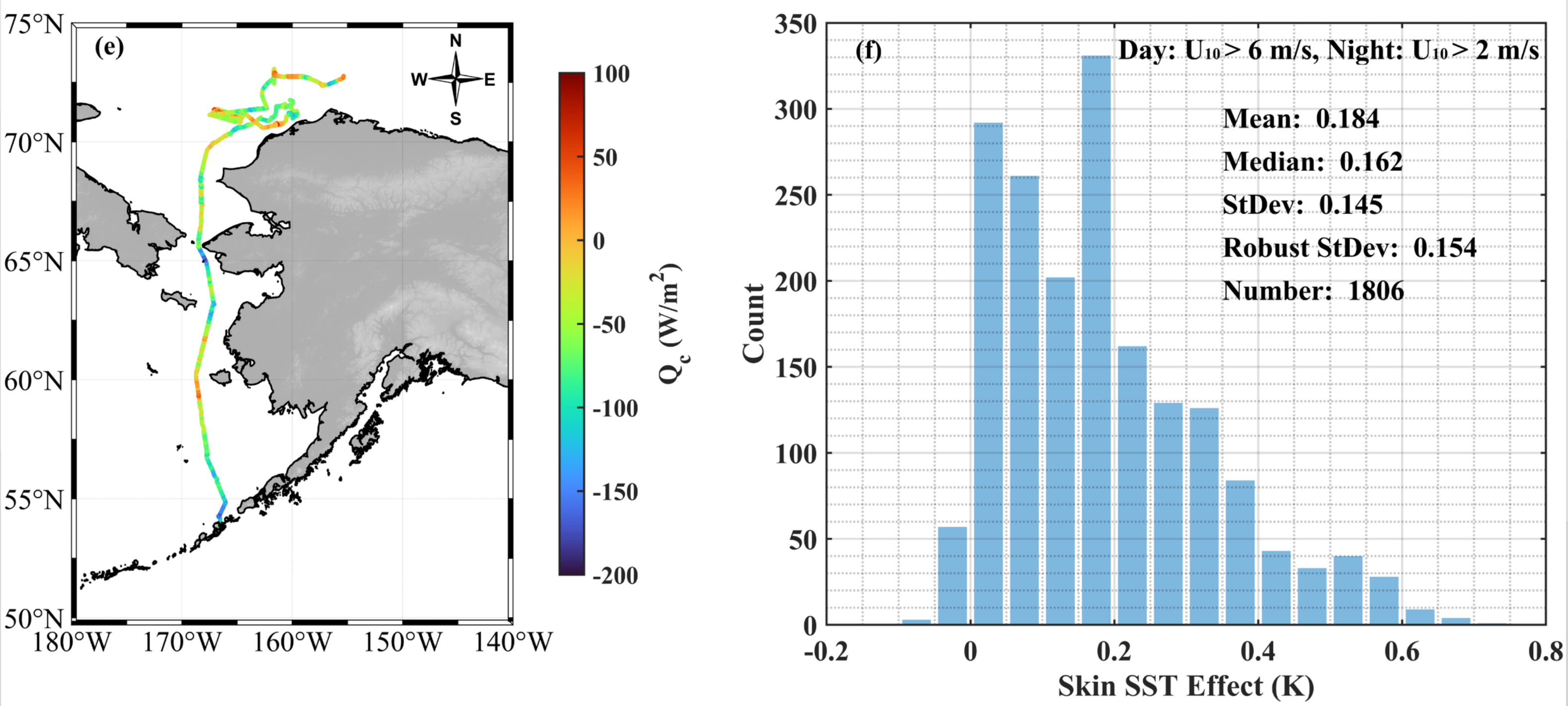




- **The rain will have lowered the salinity of a thin layer at the surface ocean, causing strong warming signals within but a delay and much weaker response in the water beneath.**
- **The cold air came from Northeast Siberia in the Arctic.**

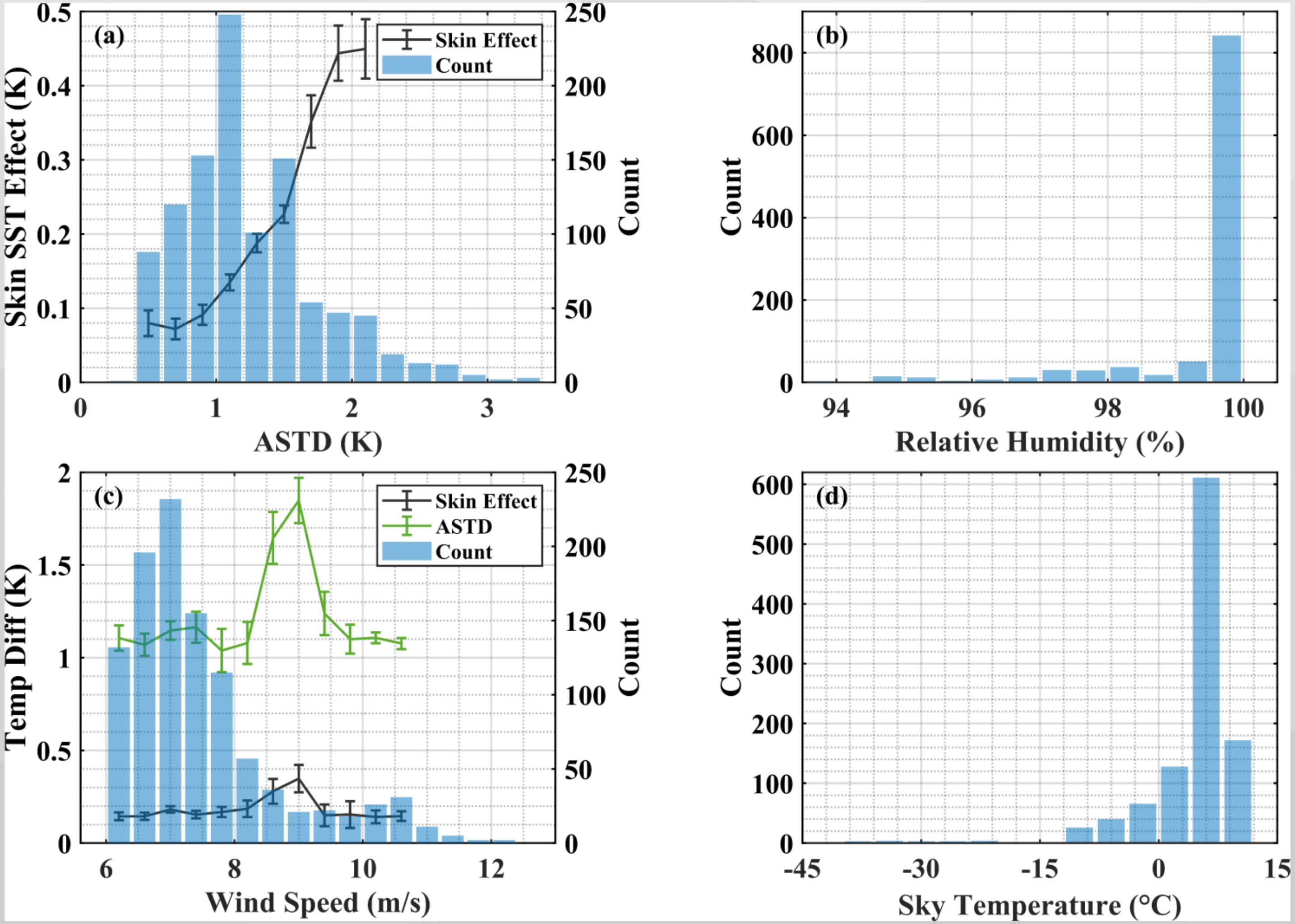
- **A less salty surface layer was likely created by melting sea ice, providing favorable conditions for the formation of upper ocean stratification.**
- **The warm air originated from the lower atmosphere over the Arctic Ocean but was heated by its passage over land.**

Identified Warm Skin Signals



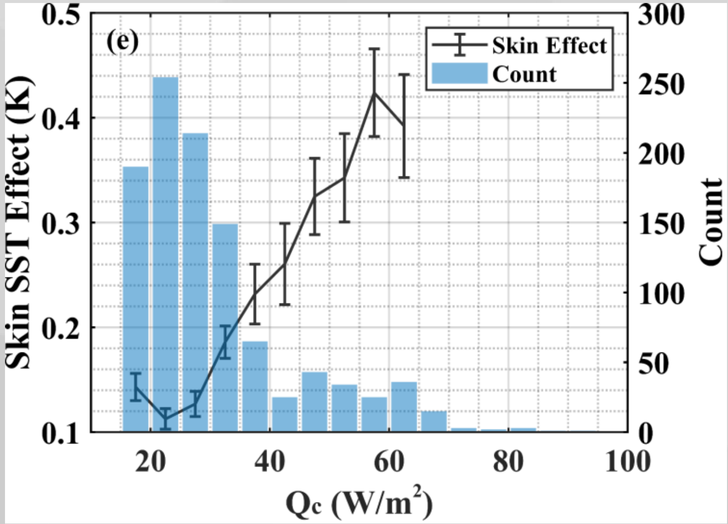
- Theoretically, the usual cool skin can be converted to warm skin by reversing the sign of Q_c, so the net heat flux is from atmosphere to ocean.
- Select 17.84 W/m^2 as the threshold for Q_c significantly > 0 mostly due to the accuracy of ERA5 $LW\downarrow$ data.
- Only keep 10 m wind speed (U_{10}) > 2 m/s at night and > 6 m/s during the day, which can be considered as well-mixed conditions, to guarantee $SST_{-0.3\ m}$ can represent $SST_{subskin}$.
- In conditions of significantly positive Q_c, over 96% skin SST effects (SST_{skin}-$SST_{-0.3\ m}$) are positive.

Characteristics of Warm Skins

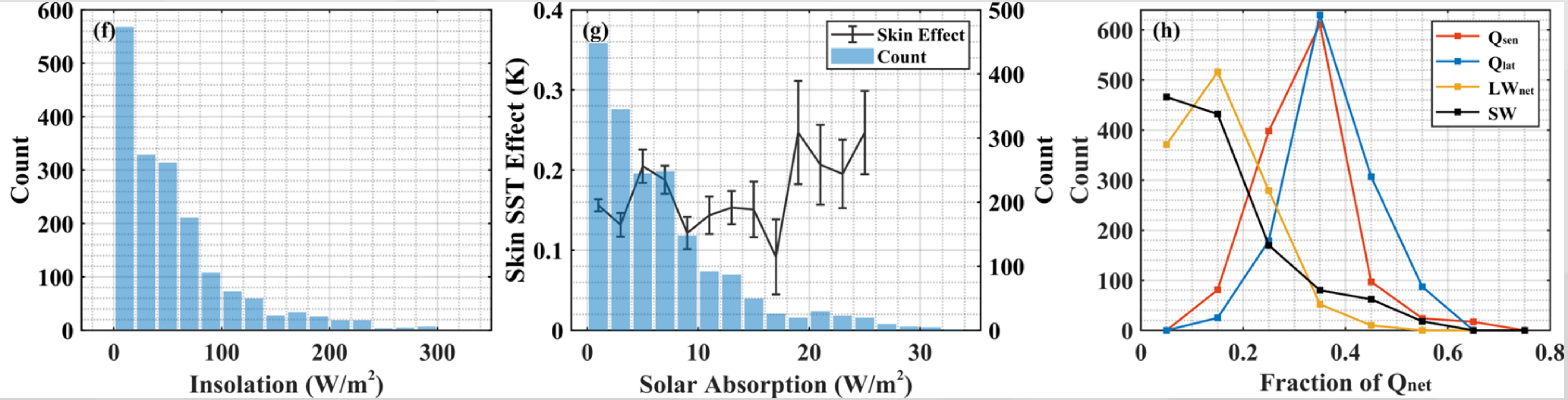


Warm skins were observed when:

- Positive air-sea temperature difference (Q_{sen})
- Humid surface air (Q_{lat})
- Cloudy sky ($LW \downarrow$)
- No obvious wind speed dependence > 6 m/s



Solar Radiation Effect on Warm Skins



- The incident solar radiation at the sea surface is generally < 100 W/m^2.
- The solar absorption in the skin layer is typically < 20 W/m^2.
- The warm skin effect does not exhibit explicit dependence on the absorbed insolation when it is < 10 W/m^2.
- Solar absorption is not the dominant cause, but the turbulent fluxes are dominant.

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4 Conclusions

Research Summary

Take Home Points

- A cool skin effect parameterization with new coefficients is derived.
- Several diurnal warming events with very large amplitudes (> 5 K), some even with long persistence, are documented.
- The local warm surface air, even warmer than skin SST, could suppress turbulent heat loss from the ocean into atmosphere, supporting the stratified upper ocean persisting into the next day.
- Reduced salinity, likely caused by precipitation or melting sea ice, plays an important part in the formation of upper ocean stratification during diurnal warming at high latitudes.
- Warm skins are mostly present with positive air-sea temperature difference and humid air under cloudy skies.
- The insolation absorption in the skin layer is a minor contributor to Q_{net}, ~16% in average, compared to the contribution of sensible (~32%) and latent (~37%) heat fluxes, and is comparable to that of LW_{net} (~15%).

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5 Future Work

Further Research

Possible Future Work

- Model schemes for diurnal warming applied at high latitudes necessarily need to be improved.
- Warm skin is often associated with the occurrence of rainfall and its contribution needs to be further studied.
- It is also necessary to investigate if warm skin exists along with diurnal warming.
- Model schemes for the warm skin necessarily need to be established.

THANKS