TURBULENCE, TRANSPORT, AND HEAT FLUXES IN DIURNAL WARM LAYERS

Direct observations from a surface-following platform

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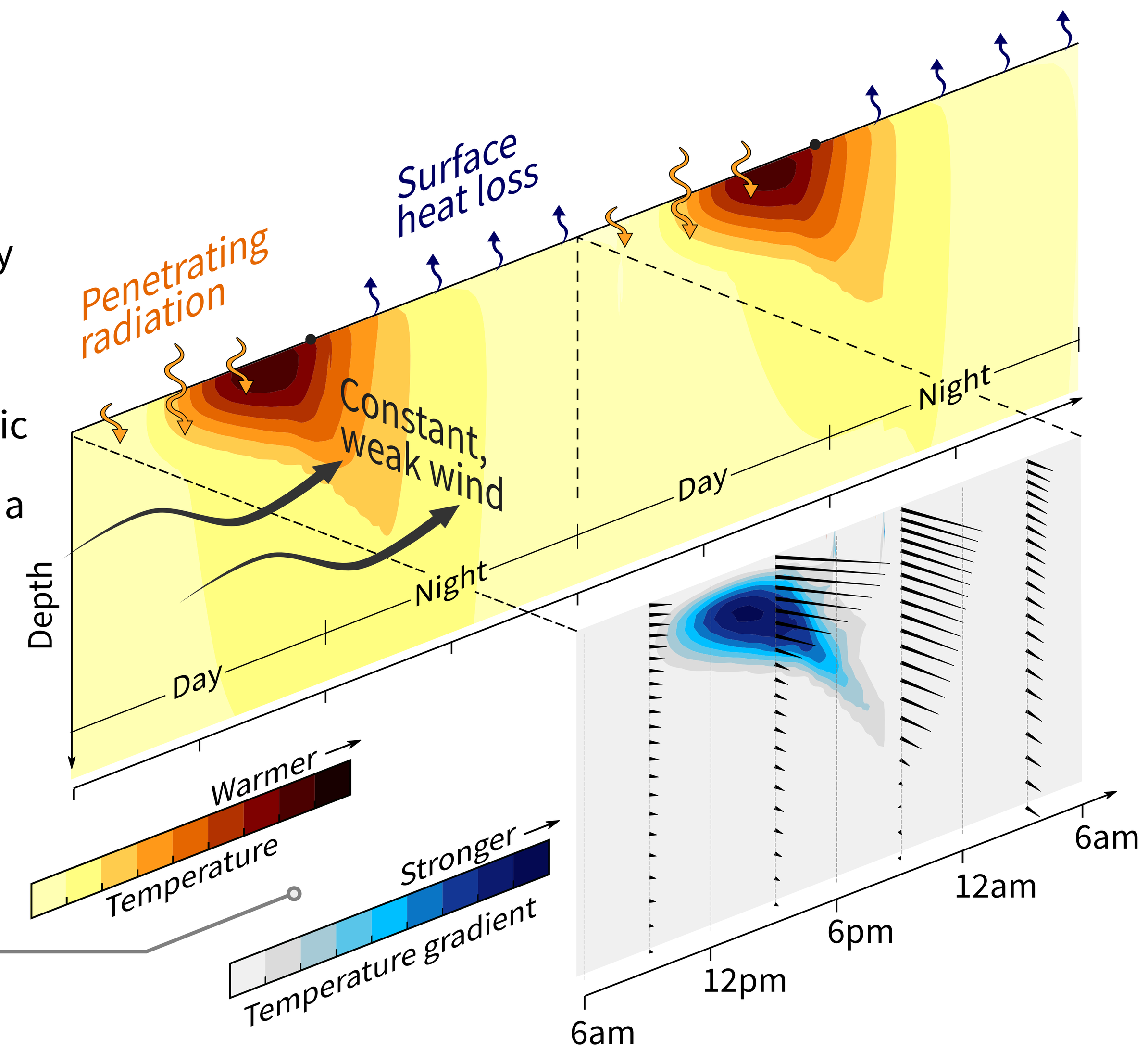
We use fast thermistors attached to a surface-following platform to infer the diurnal evolution of turbulence dissipation ε and turbulent heat fluxes between the surface and 8 m deep. Beneath the maximum diurnal stratification, ε decreases by more than two orders of magnitude. The associated reduction in eddy diffusivity leads to heat convergence where stratification is strongest.

INTRODUCTION

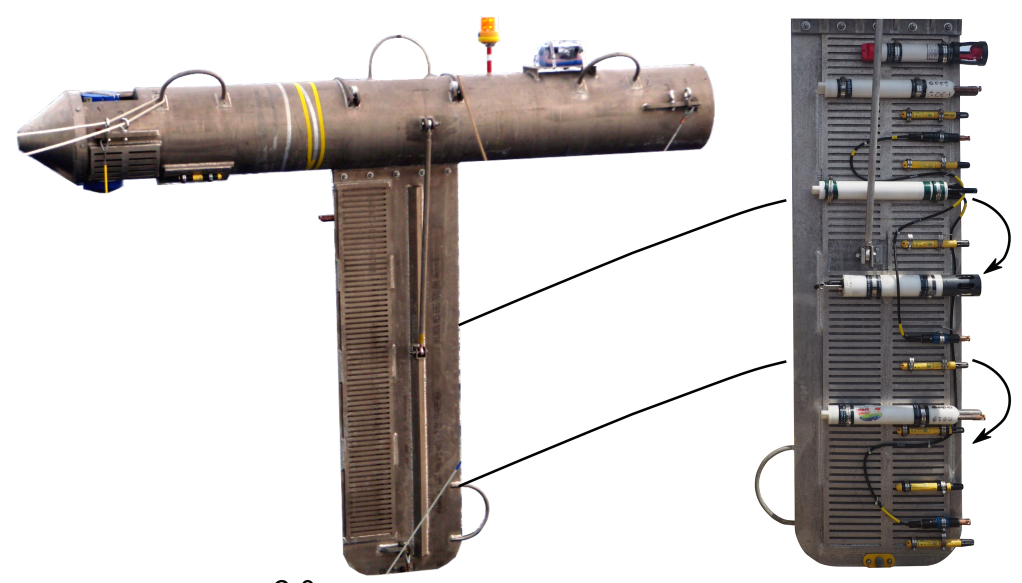
- Diurnal warm layers form in weak-to-moderate winds (< 8 m s^{-1}) on clear-sky days
- Daytime increases in SST of 1°C are common throughout the tropical Pacific
- Subsurface turbulent heat transport is a large but poorly quantified part of the surface heat budget

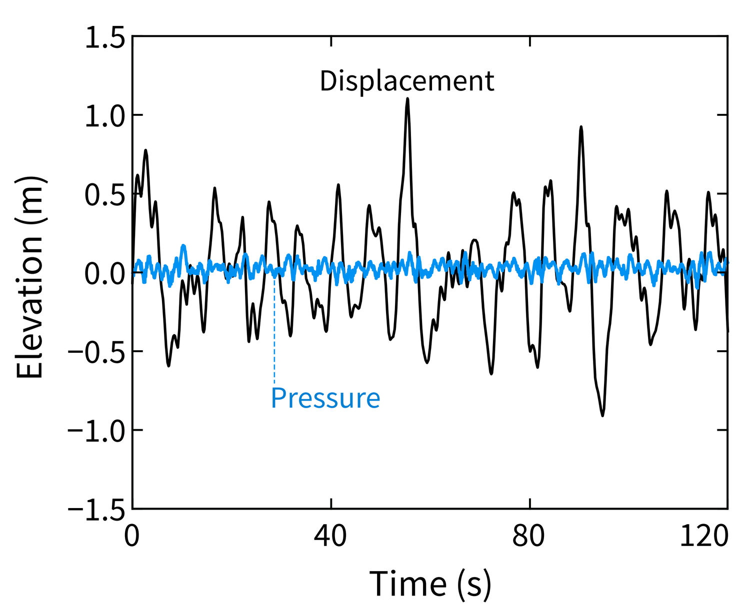


Trapping of heat and momentum in a DWL
An otherwise well mixed layer is forced by a weak wind. The addition of periodic penetrating solar radiation and heat loss induces near-surface stratification and, consequently, shear because the now-warmed layer traps the momentum input from wind.

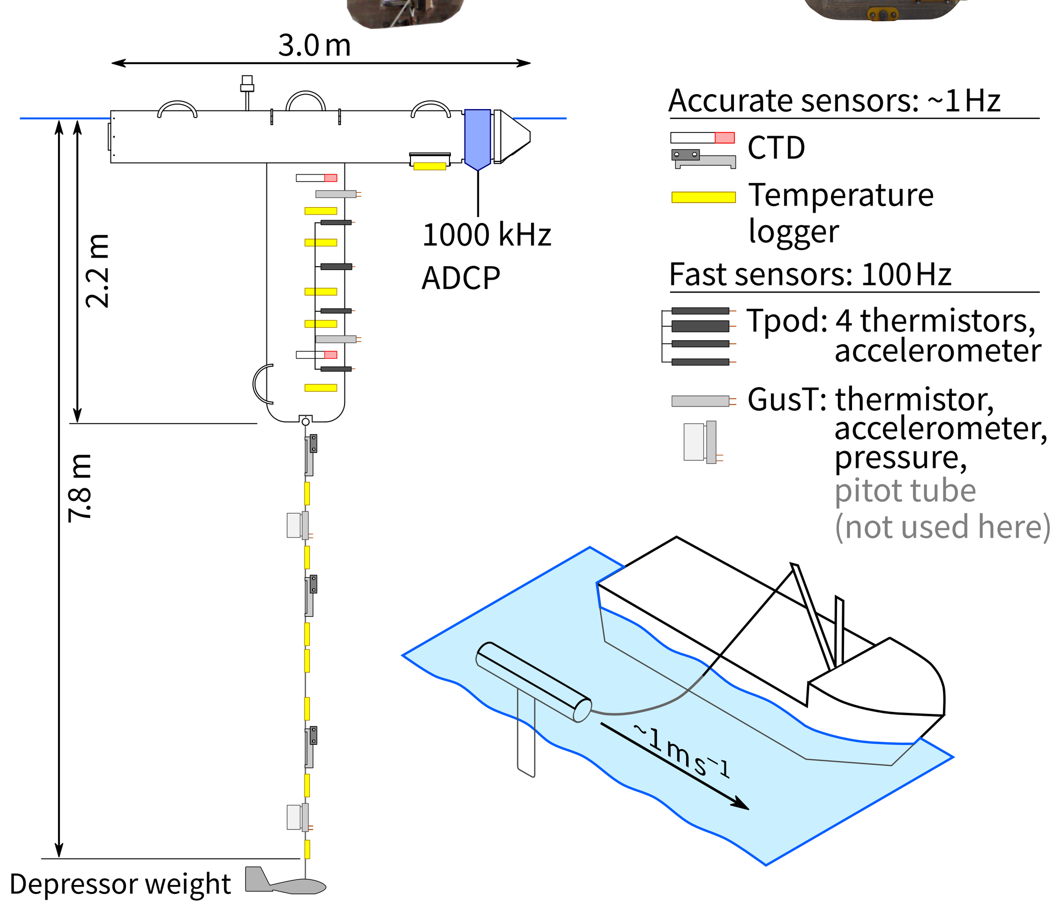
INSTRUMENTATION

- SurfOtter: a surface-following platform towed outside the ship's wake
- Designed for measurements of near-surface velocity, temperature, salinity, and turbulence
- Has recorded 40 days of data at sites between 12 and 18°N in the tropical western Pacific in 2018 and 2019



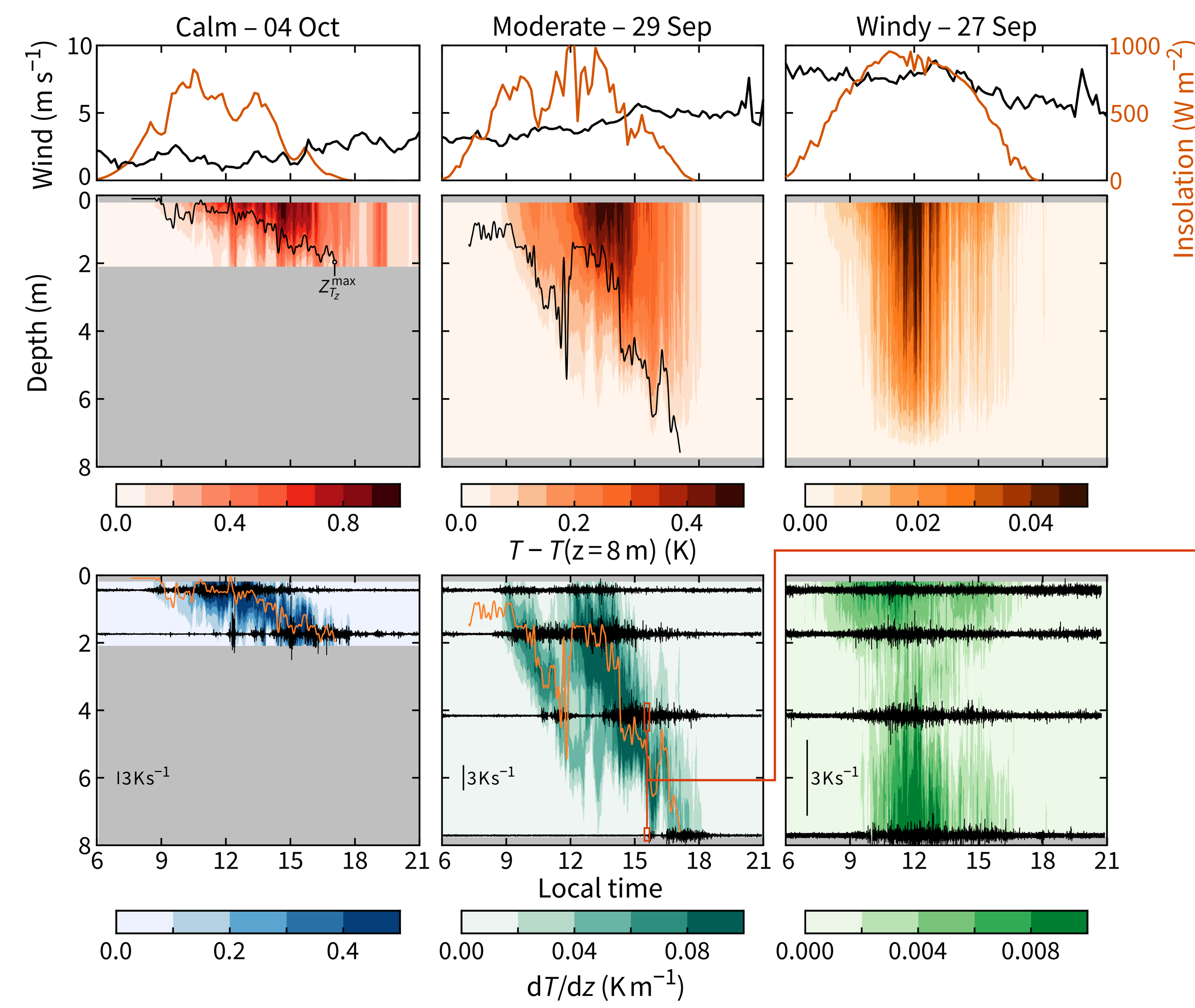


Sensors follow the surface to within ±5 cm
Comparison of pressure measured at the bottom of the fin with the vertical displacement of SurfOtter as determined from accelerometers.



WIND CONTROLS WARM LAYER STRUCTURE

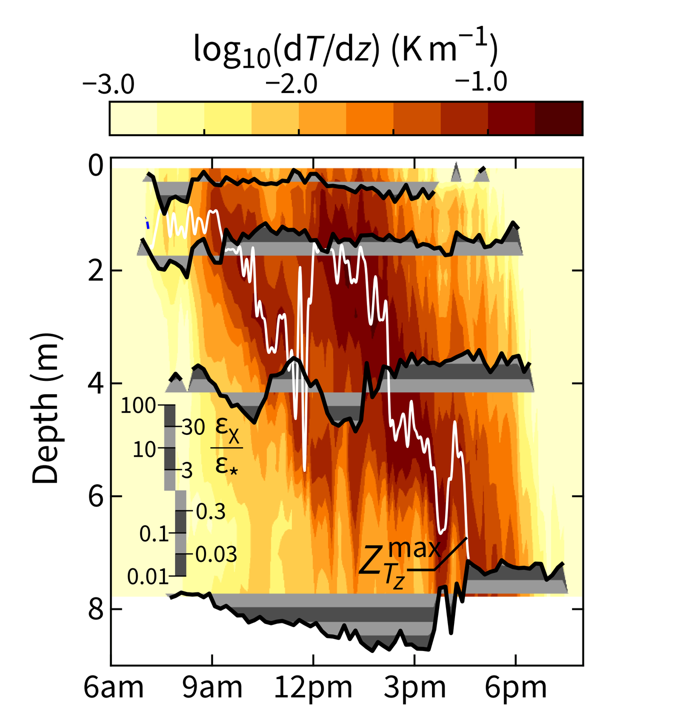
- Under calm winds (<3 m s^{-1}), the diurnal temperature gradient is strong (~0.5°C m^{-1})
- Under moderate winds (3–6 m s^{-1}), the warm descends at 1 m hr^{-1}
- With 7 m s^{-1} winds, SST anomalies are only 0.05°C



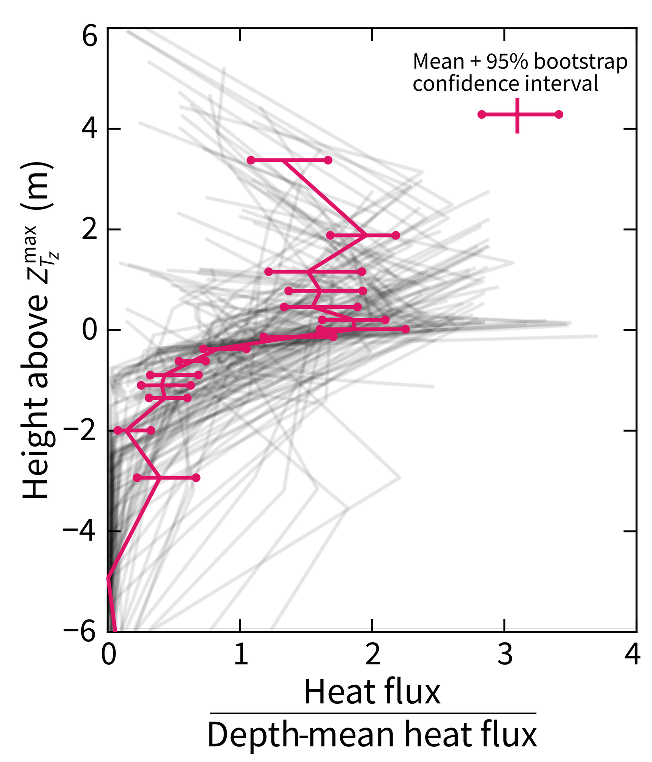
Measured temperature structure and microstructure under differing winds
Black traces in the bottom rows indicate dT/dt from fast thermistors.

DIURNAL STRATIFICATION CONFINES TURBULENCE AND HEAT FLUXES

- ε is large, $O(10^{-6}\,\mathrm{W\,kg^{-1}})$, in and above the diurnal temperature gradient due to the induced shear, but small beneath due to decoupling from atmosphere
- Turbulent heat fluxes are largest at and above the peak temperature gradient



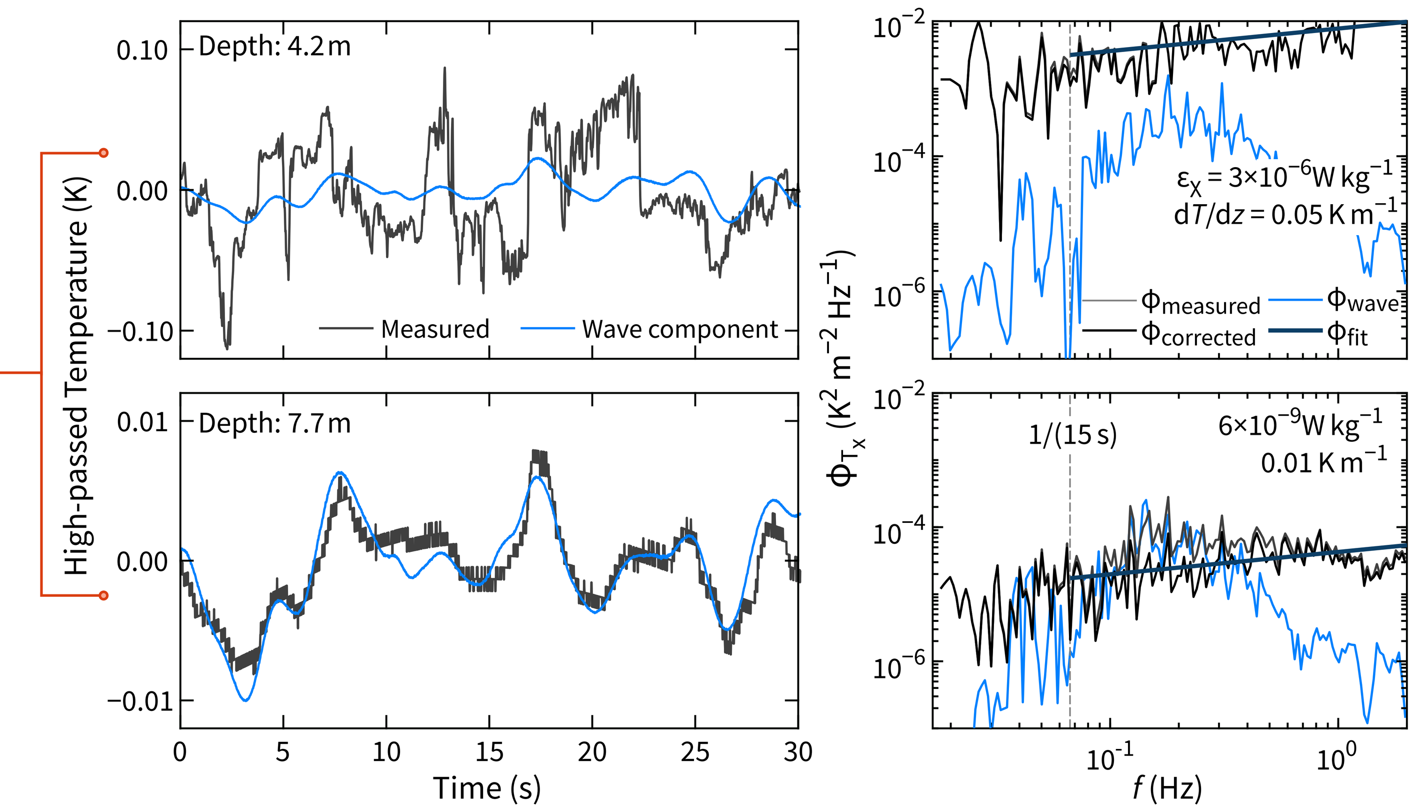
Enhanced and suppressed turbulence dissipation above and below the warm layer
Data from the moderate day in the figure above. The relative enhancement of the measured value, ε_χ, is presented as a logarithmically scaled ratio with a wind-dependent scaling, ε_*.



Non-dimensionalized heat fluxes from all days when the peak dT/dz could be discerned

DERIVING DISSIPATION FROM FAST THERMISTORS

- Time series of horizontal temperature gradient are separated into 10-minute blocks
- Spectra are fit over the inertial–convective band
- The temperature signal due to surface waves is derived and then its influence is removed spectrally

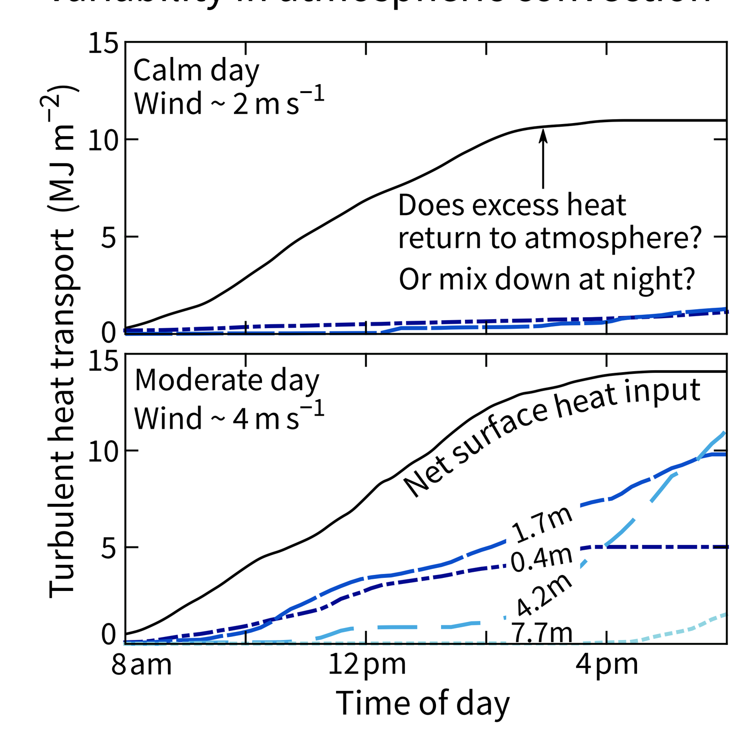


Temperature time series and spectra within and below the diurnal temperature gradient
This example is from the moderate day at 3:30 pm at (top) 4.2 m (bottom) 7.7 m.

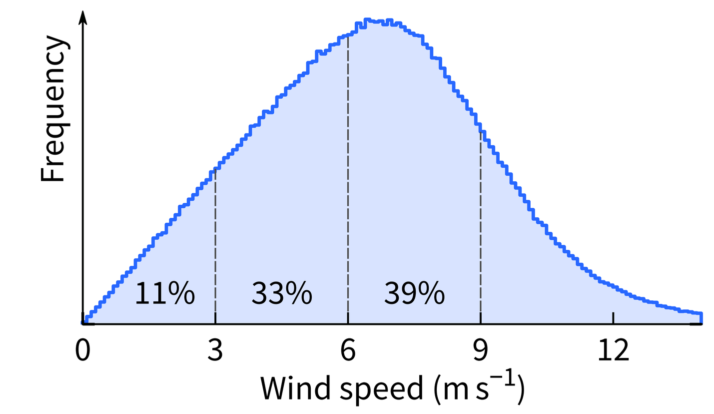
POTENTIAL CONSEQUENCES

- Induced shear drives daytime peak in ε
- Masking of horizontal temperature gradients (Katsaros et al., 2005)
- Submesoscale mixing (Bogdanoff, 2017)
- Increased SST may drive diurnal variability in atmospheric convection
- Combine measured warm layer thickness and duration (functions of wind speed) with wind-speed reanalyses and typical current speeds to estimate transport by warm layers

For a section 23°S to 23°N, transport by warm layers on
- calm days: 0.04 Sv
- moderate days: 0.5 Sv
- windy days: 0.6 Sv



Integrated turbulent heat fluxes through fixed depths



Wind speeds over the ocean in the tropics

RELATED STUDIES

- The forerunner to this study
  Moulin et al. (2018, JPO)
- Inertial turning of warm-layer shear
  Hughes et al. (2020, JPO)
- Description of GusT profilers
  Becherer et al. (under review, JPO)
- Submesoscale mixing by warm layers
  Bogdanoff (2017, PhD Thesis)
- Enhanced turbulence within warm layers
  Sutherland et al. (2016, JPO)
- Masking of mixed layer gradients
  Katsaros et al. (2005, BLM)