Diurnal sea surface temperature drives turbulence in the tropical atmospheric mixed layer

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Abstract

Absorption of sunlight forms a diurnal warm layer (DWL) in the afternoon at the surface and upper meters of the ocean when wind is weak. Analyses using models and remote sensing data disagree on the frequency of DWLs stronger than 1 °C. In situ time series in the central Indian Ocean showed the DWL exceeded 1 °C for 24% of days in October-December 2011 during the Dynamics of the Madden Julian Oscillation (DYNAMO) experiment. For 4 days with mean wind of 1.4 m/s, the DWL was 1.5-2.5 °C. We observed atmospheric turbulence over the DWL using Doppler lidar. Mixed layer turbulence is convective, generated mostly by surface buoyancy flux. The turbulent kinetic energy dissipation of the convective marine atmospheric mixed layer scales with surface buoyancy flux like diurnal convective boundary layers over land and convective mixed layers in the ocean and lakes. This convection in the afternoon is out of phase with buoyancy flux from nocturnal atmospheric net radiative cooling. The afternoon atmospheric convective turbulence over the tropical ocean mixes heat and humidity from the ocean to the lifted condensation level of clouds.

Diurnal SST drives turbulence and clouds in the marine atmospheric mixed layer

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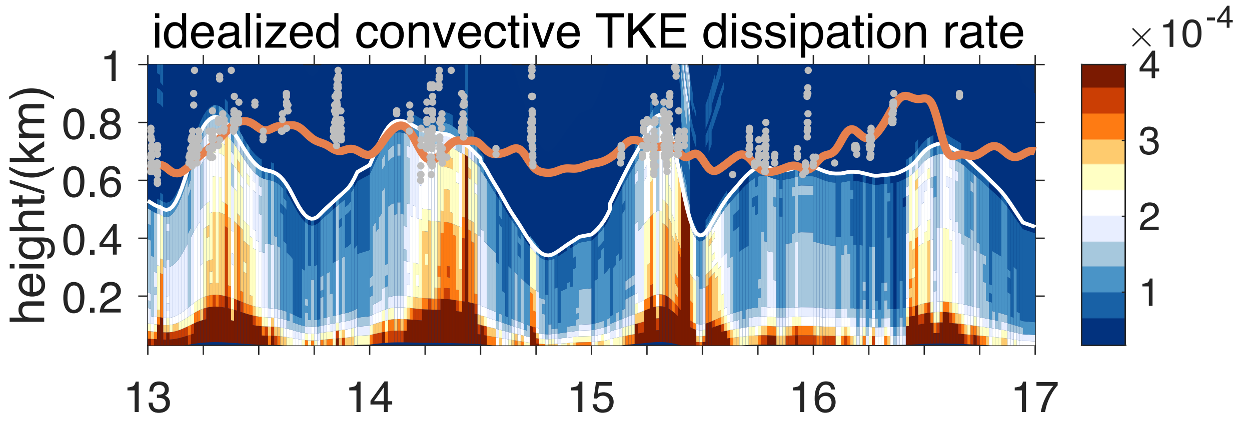

A103: *Atmosphere, Ocean, and Land Processes in the Maritime Continent and Indo-Pacific I*
Thursday, **10 December 2020, 17:30 - 18:30 PST** (UTC-8)
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Outline

1. Introduction

   Previous work, Observations and methods

2. Results
   - Warm afternoon SST increases buoyancy flux.
   - Turbulent kinetic energy dissipation rate is proportional to buoyancy flux in marine convective mixed layers.
   - These turbulent mixed layers form clouds when they reach the lifting condensation level.

1. Introduction

- Afternoon convection generates cumulus clouds over land and ocean.

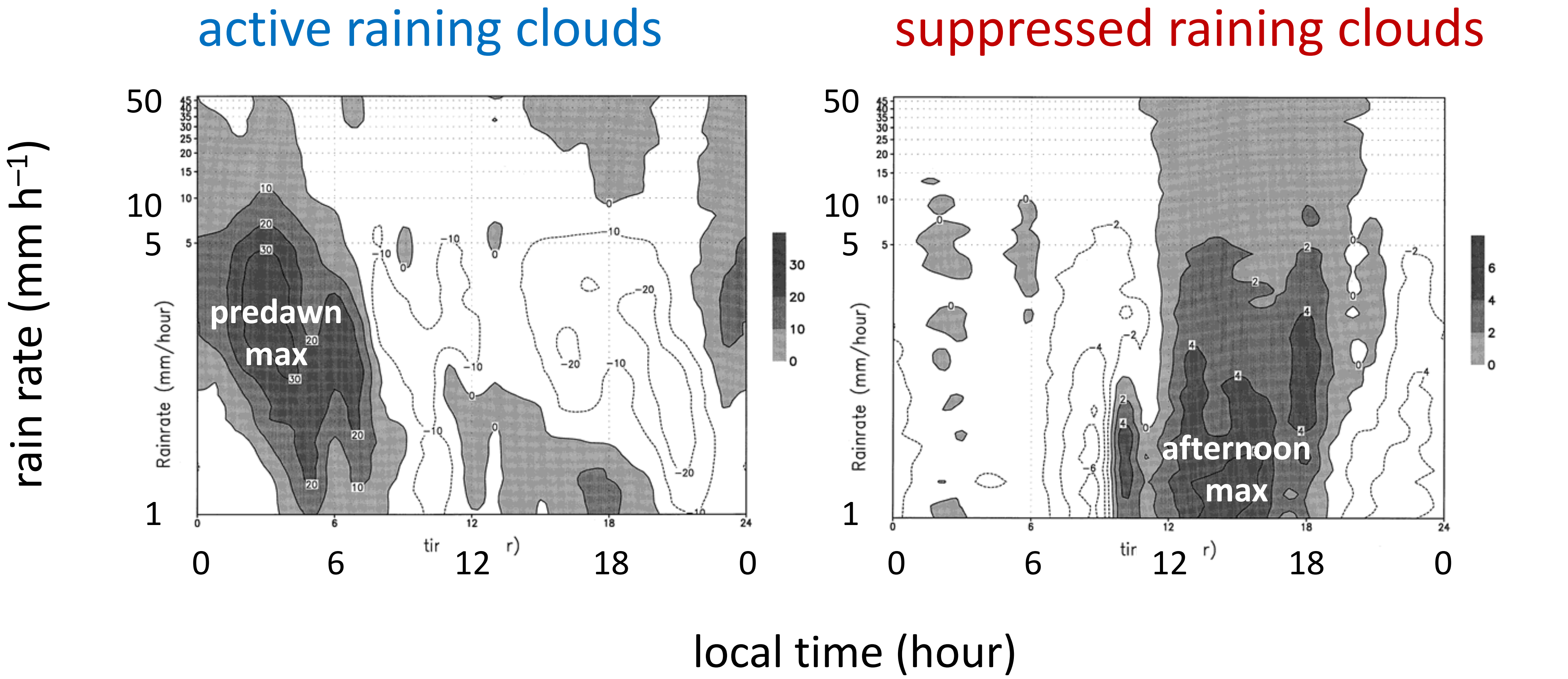
- Diurnal sea surface temperature (SST) warming (dSST)
  - Diurnal SST is warmer for weaker wind.
  - Its distribution varies among analyses.
  - Diurnal SST range > 1 °C covers vast and changeable areas → 2% of Earth's surface.

- DYNAMO 2011 observations and methods

[The ***cumulus***] appearance, increase, and disappearance in *fair* weather, are often periodical, and keep pace with the Temperature of the day. Thus they will begin to form some hours after sun-rise, arrive at their maximum in the hottest part of the afternoon, then go on diminishing, and totally disperse about sun-set.

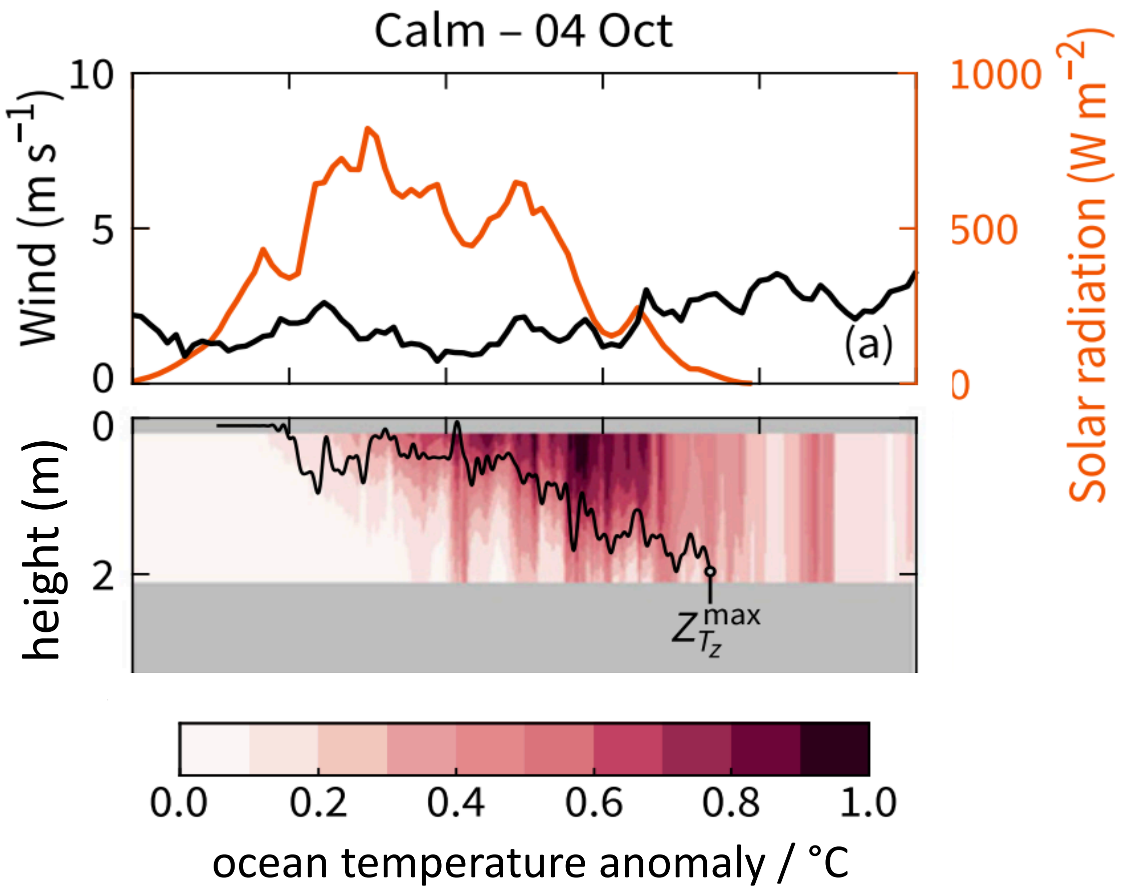
—Luke Howard, 1803,
Modifications of clouds

Ocean diurnal cycle of rain over ocean in **active** vs. **suppressed** intraseasonal phases



Sui et al. 1997

Solar radiation warms top meter of ocean ~1 °C over under calm winds.



SST warming is stronger for calm winds.

Hughes et al. 2020

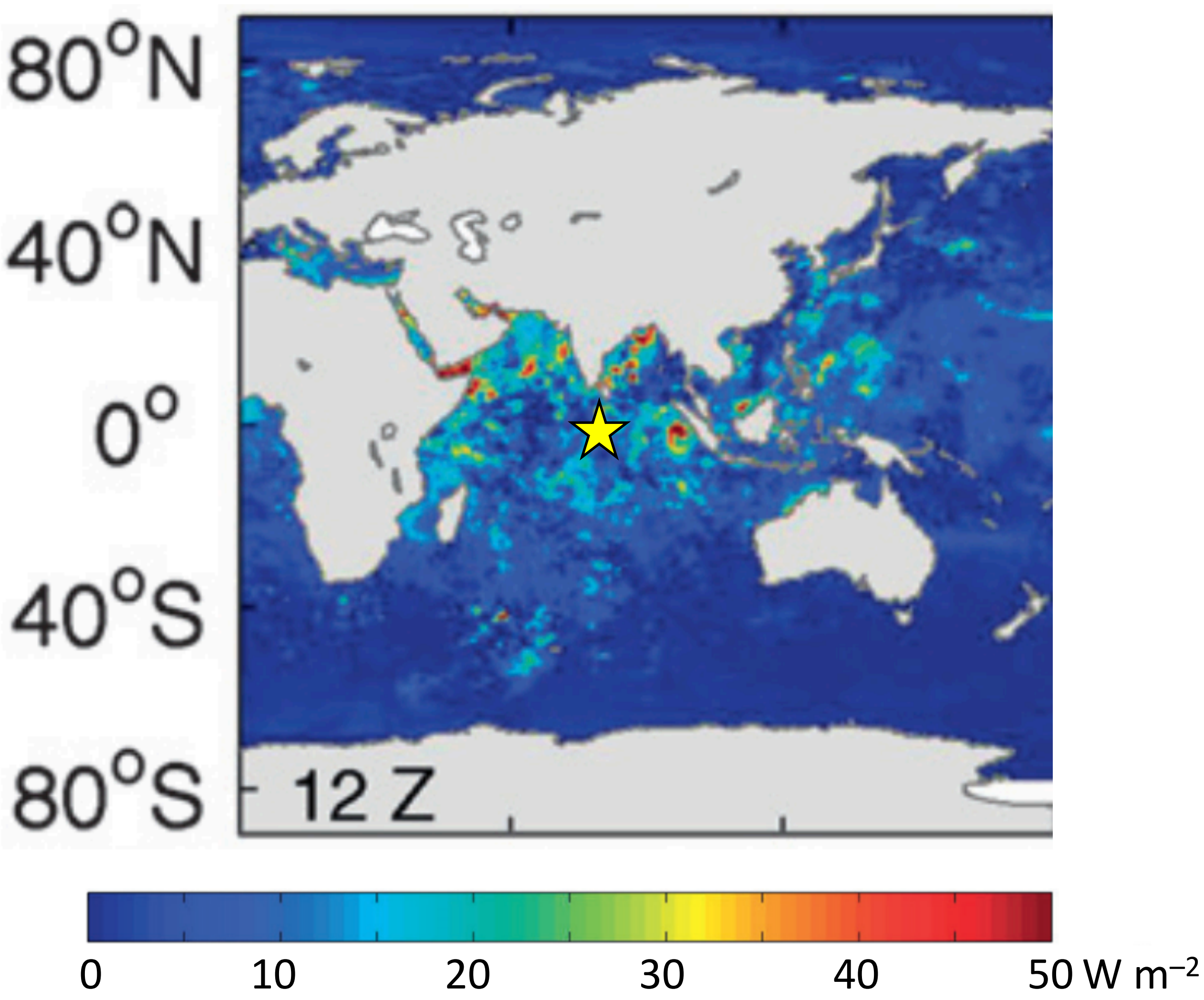
Diurnal SST range

- varies among analyses,
  especially for strong cases.

- covers vast and changeable areas.
  5% of days from tropical buoys have diurnal SST range > 1 °C
  (Prytherch et al. 2013)
  → Diurnal SST range > 1 °C covers 2% of Earth's surface.

Net heat flux anomalies from afternoon SST warming

Diurnal SST generates heat flux anomalies over oceans.



Clayson and Bogdanoff 2013

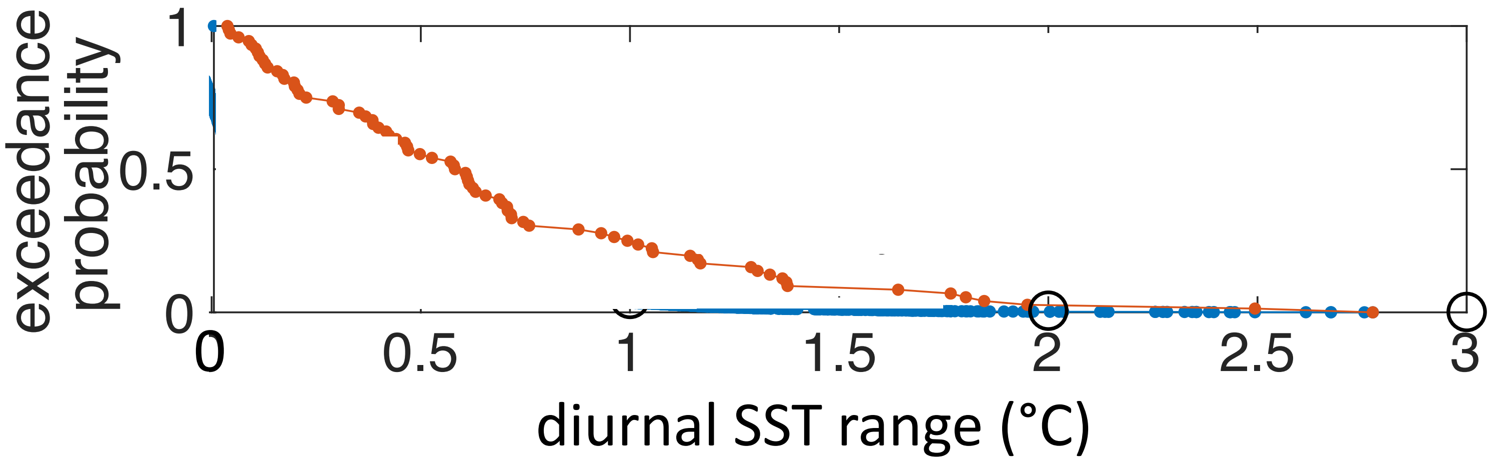
DYNAMO research cruise

Indian Ocean, equator, 80.5 °E October 2011 – January 2012

Observations:

- Surface meteorology, SST, radiative and turbulent fluxes
- Doppler lidar measures radial air velocity sampled at 2 s^{-1}
- Clouds from lidar ceilometer

Of 77 days, 7 days have SST range > 1.5 °C.

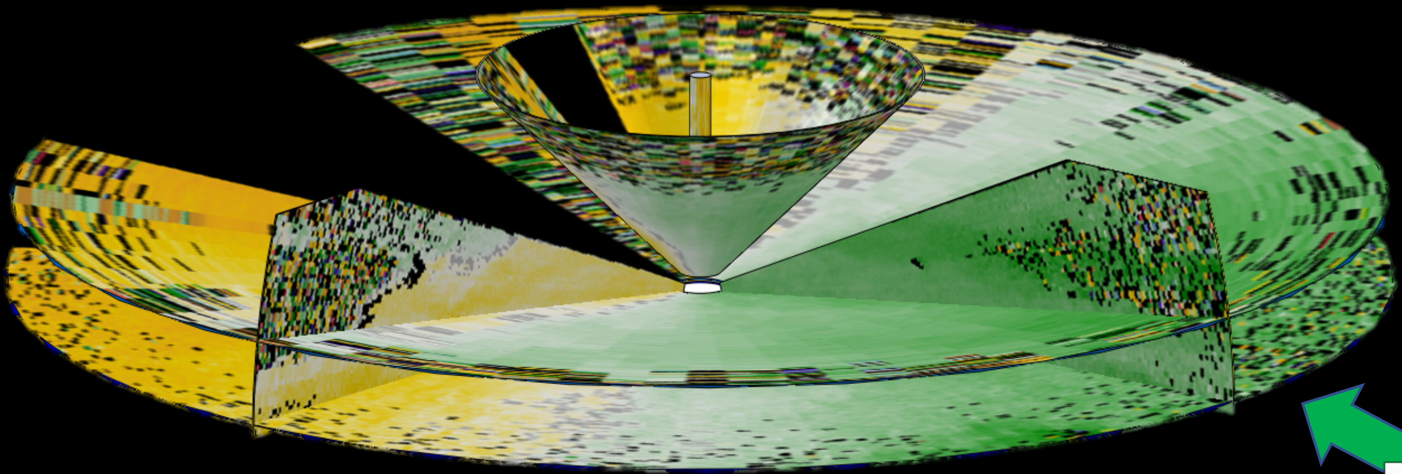


NOAA ESRL Chemical Sciences Laboratory
High Resolution Doppler Lidar

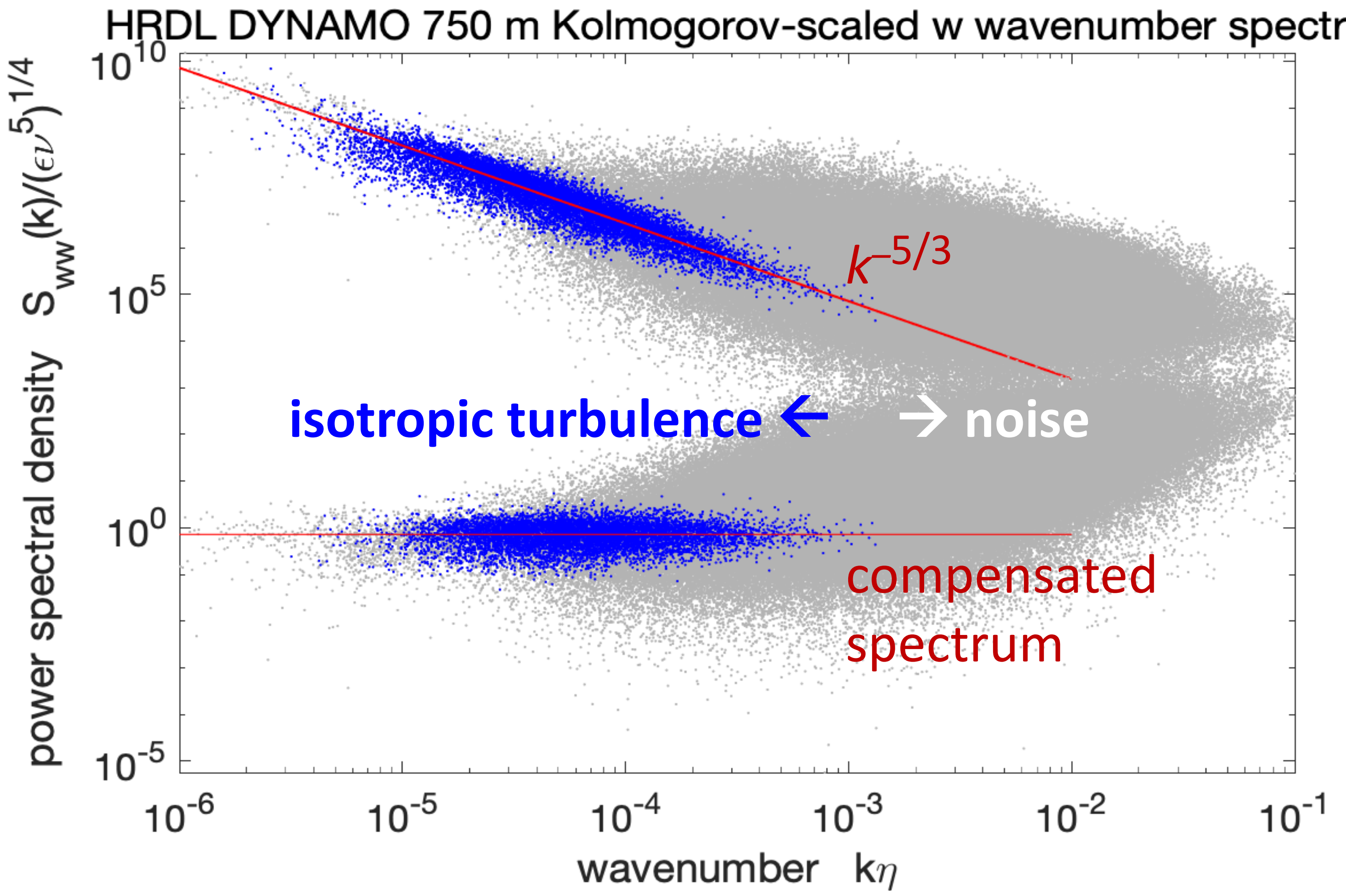
scan sequence

$2\ s^{-1}$ sampling frequency

30 m range resolution



Method: zenith-stare vertical velocity spectra → TKE dissipation rate ϵ



Find ϵ from spectral estimates

$$S(k) = C\epsilon^{2/3}k^{-5/3}$$

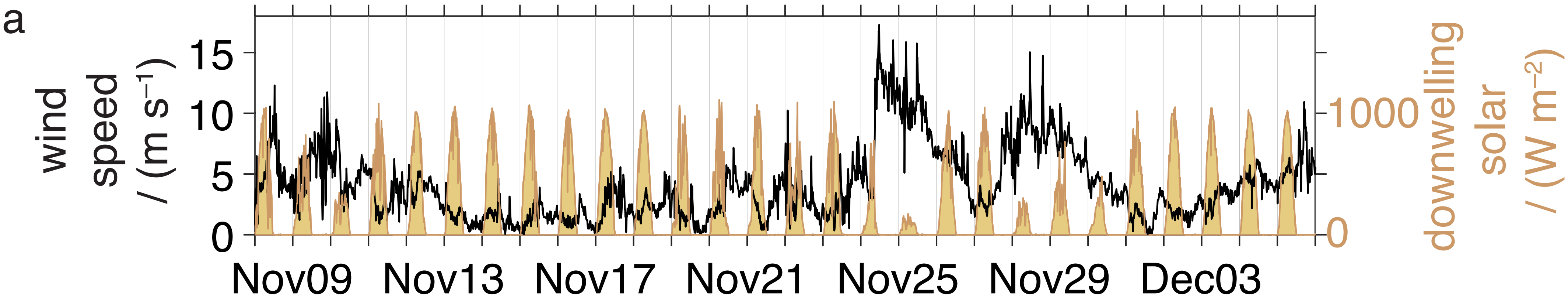
in isotropic turbulence.

2. Results

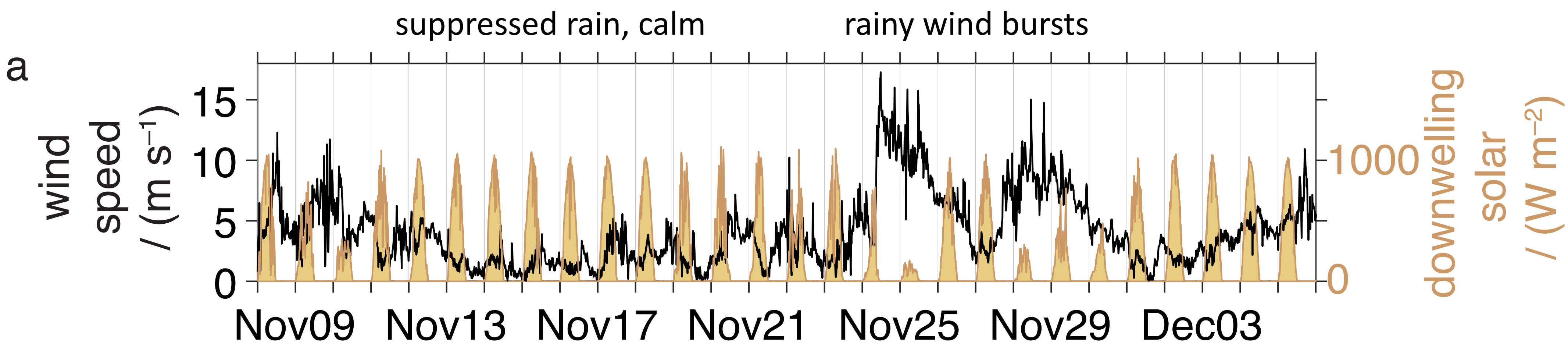
- Warm afternoon SST modulates buoyancy flux.

- Turbulence kinetic energy (TKE) dissipation rate in diurnally-varying marine convective mixed layers is proportional to surface buoyancy flux.

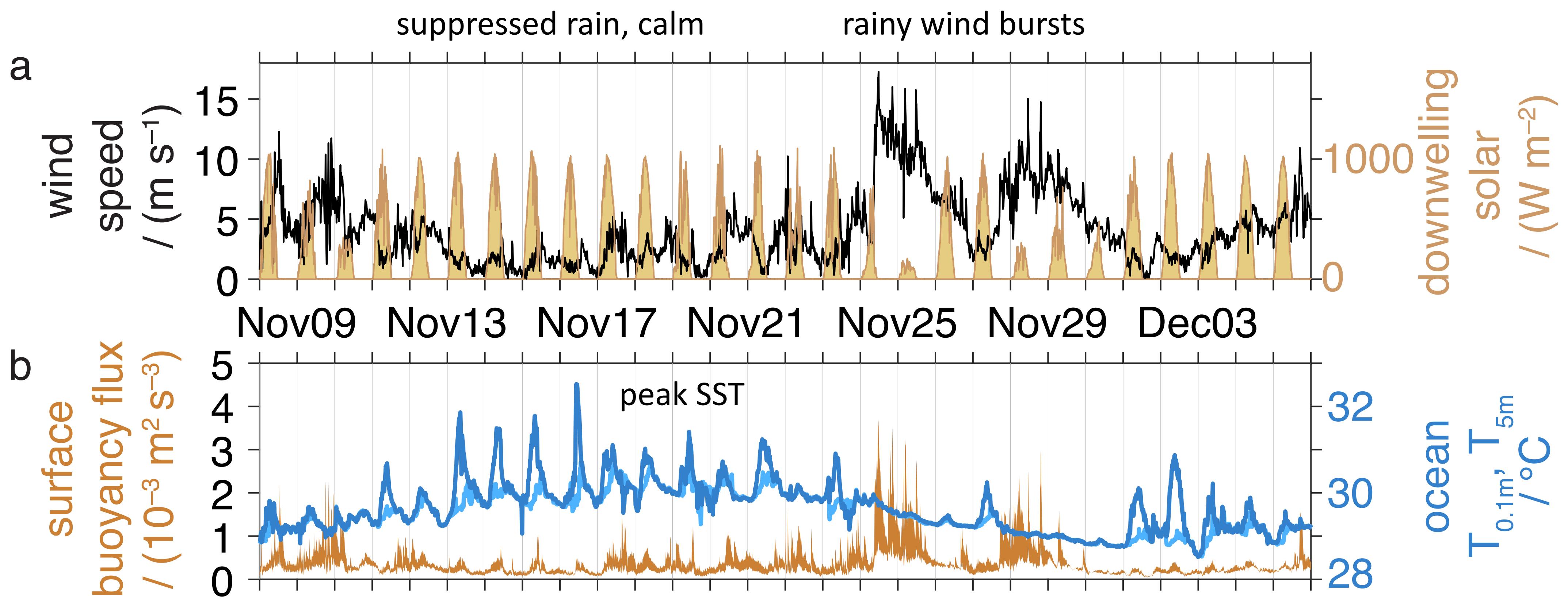
- Mixed layers form clouds when they reach the lifting condensation level.



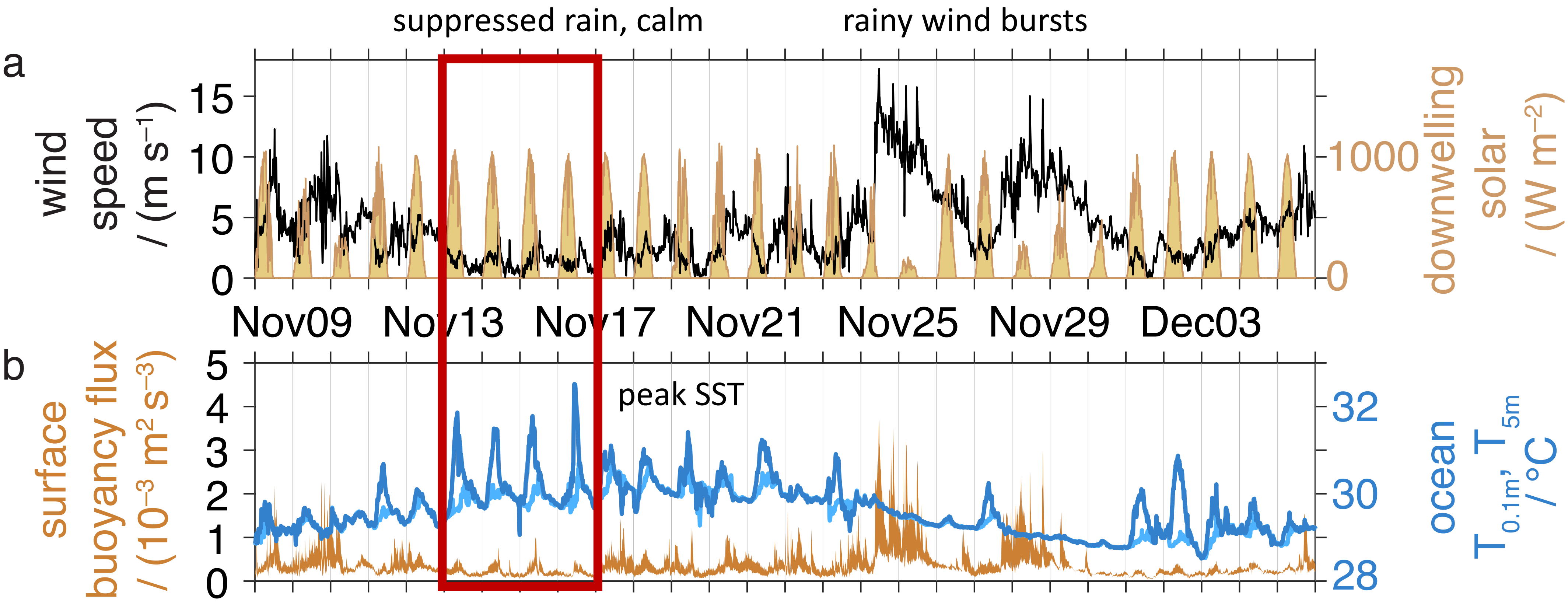
November 2011 DYNAMO research cruise, central Indian Ocean



November 2011 DYNAMO research cruise, central Indian Ocean



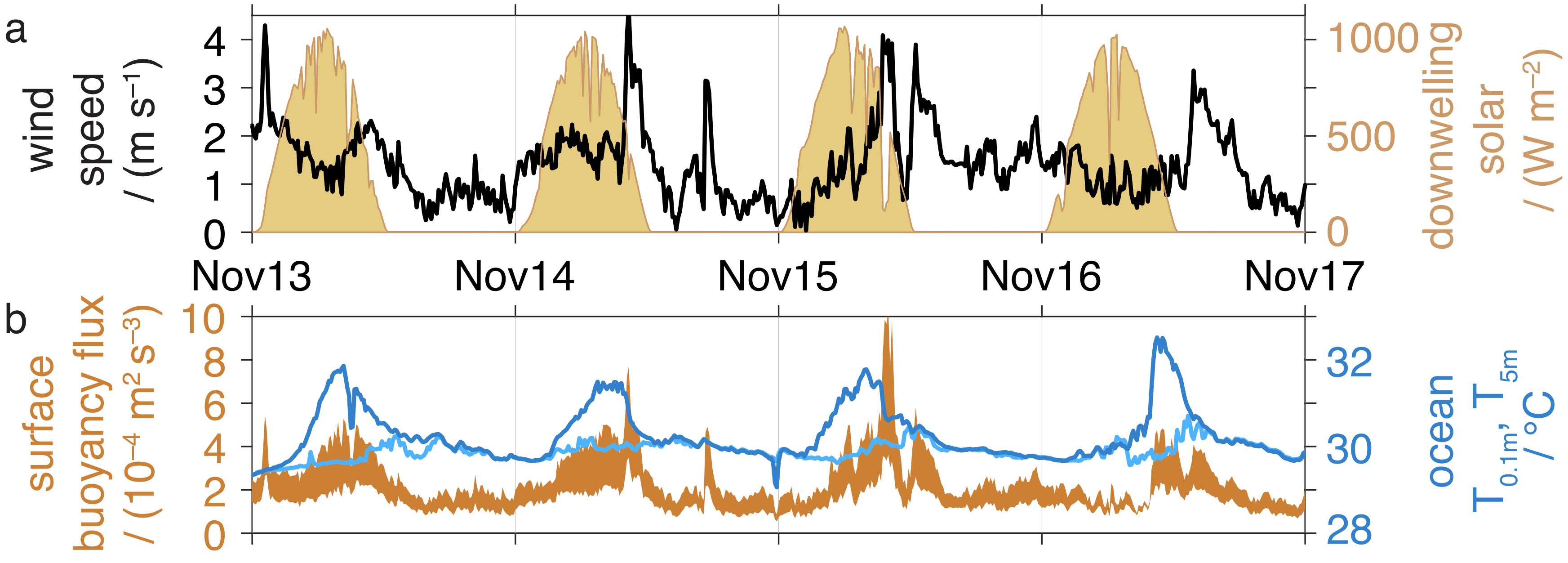
November 2011 DYNAMO research cruise, central Indian Ocean



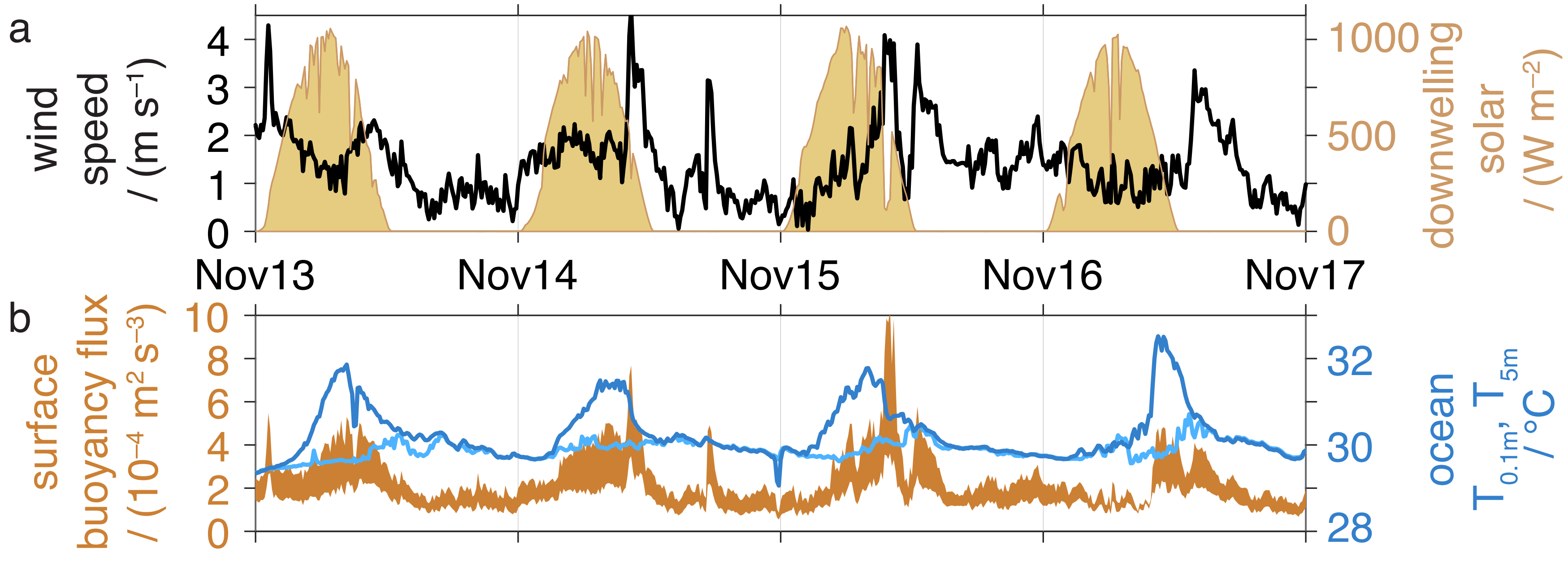
Suppressed rain, strong diurnal cycle of SST Nov 13-17

November 2011 DYNAMO research cruise, central Indian Ocean

Diurnal SST days, Nov 13-17

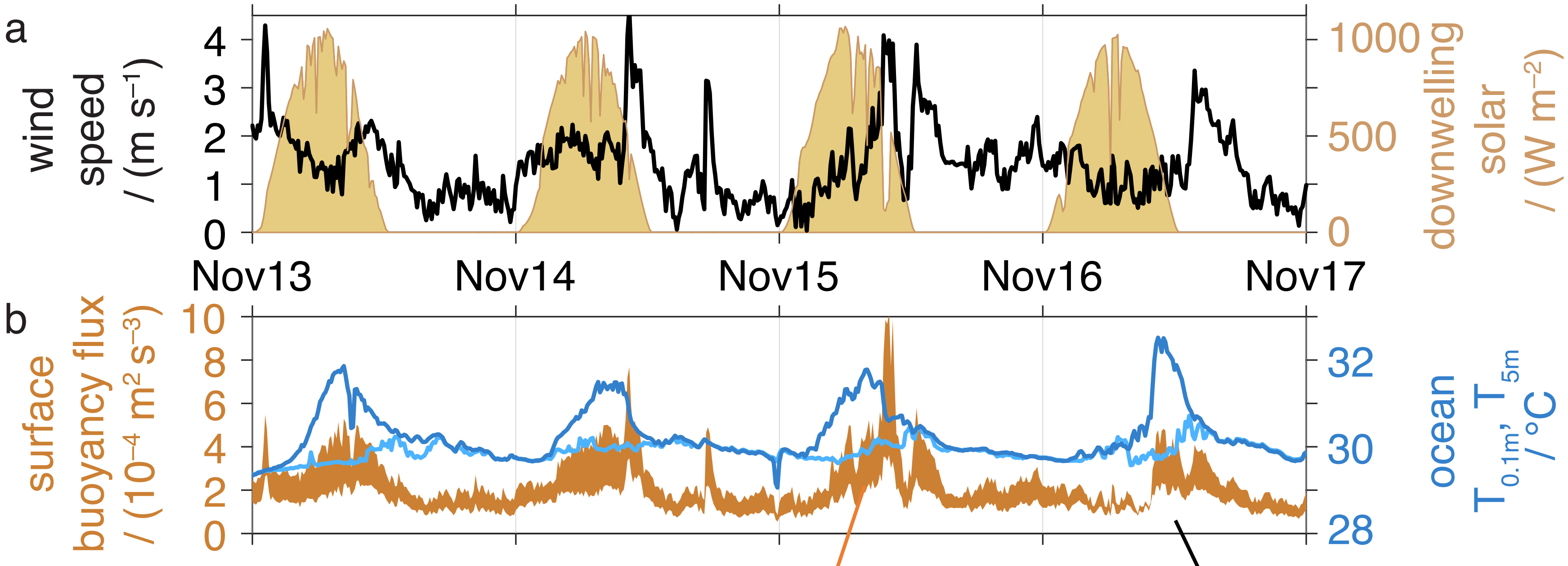


Diurnal SST days, Nov 13-17



- Correlation coefficient $R(SST, B) = 0.7$

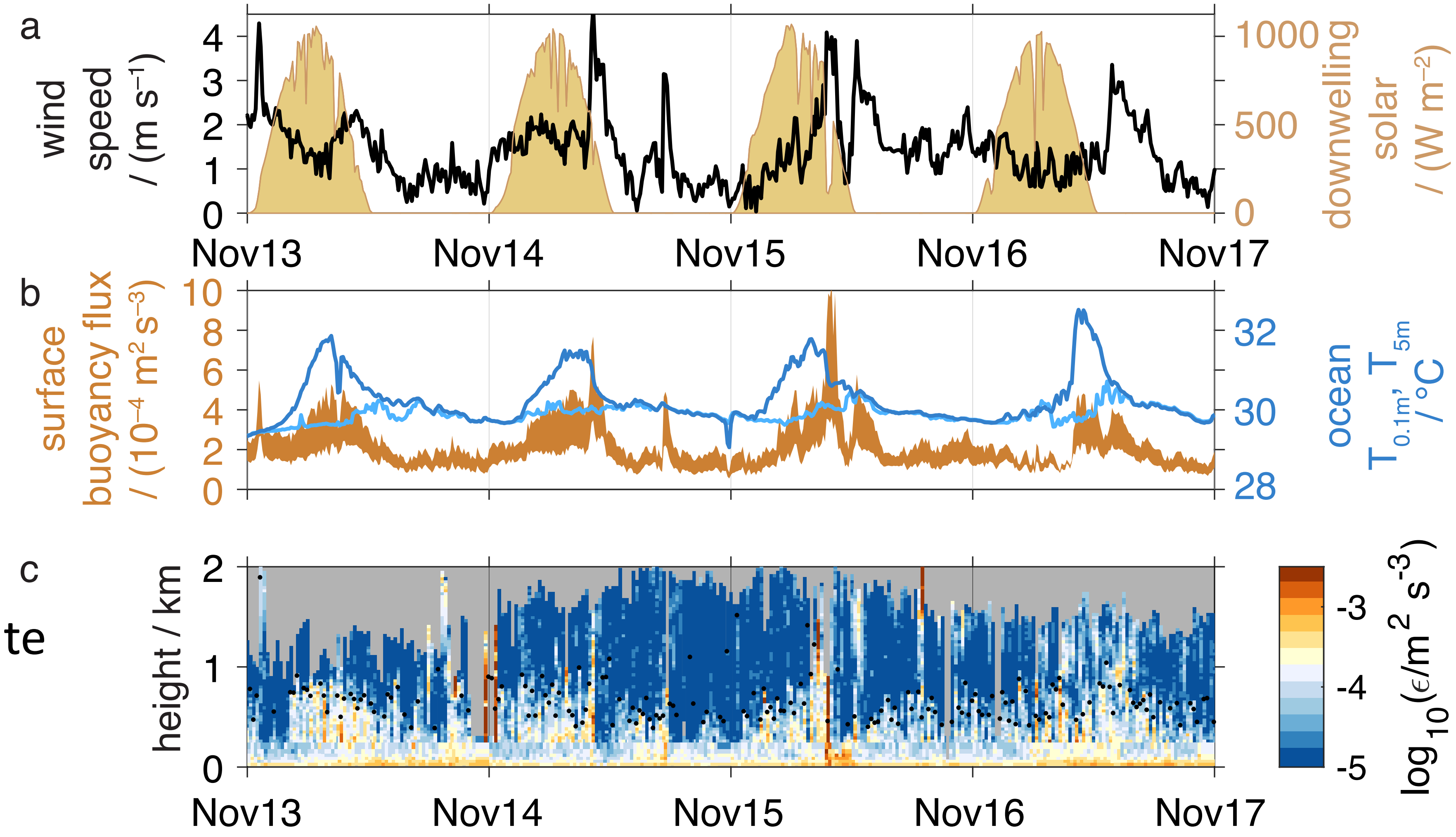
Diurnal SST days, Nov 13-17



$$B(0) = \frac{g}{T_v}\overline{w'T_v'} = \frac{g}{T_v}\left[\overline{w'T'}(1+\beta q) + \overline{w'q'}\beta T\right]$$

- Correlation coefficient $R(SST, B) = 0.7$
- Flux of temperature and water vapor contribute to buoyancy flux (Chou and Zimmerman 1989, Thompson et al. 2019).
- Here, the water vapor part varies more.

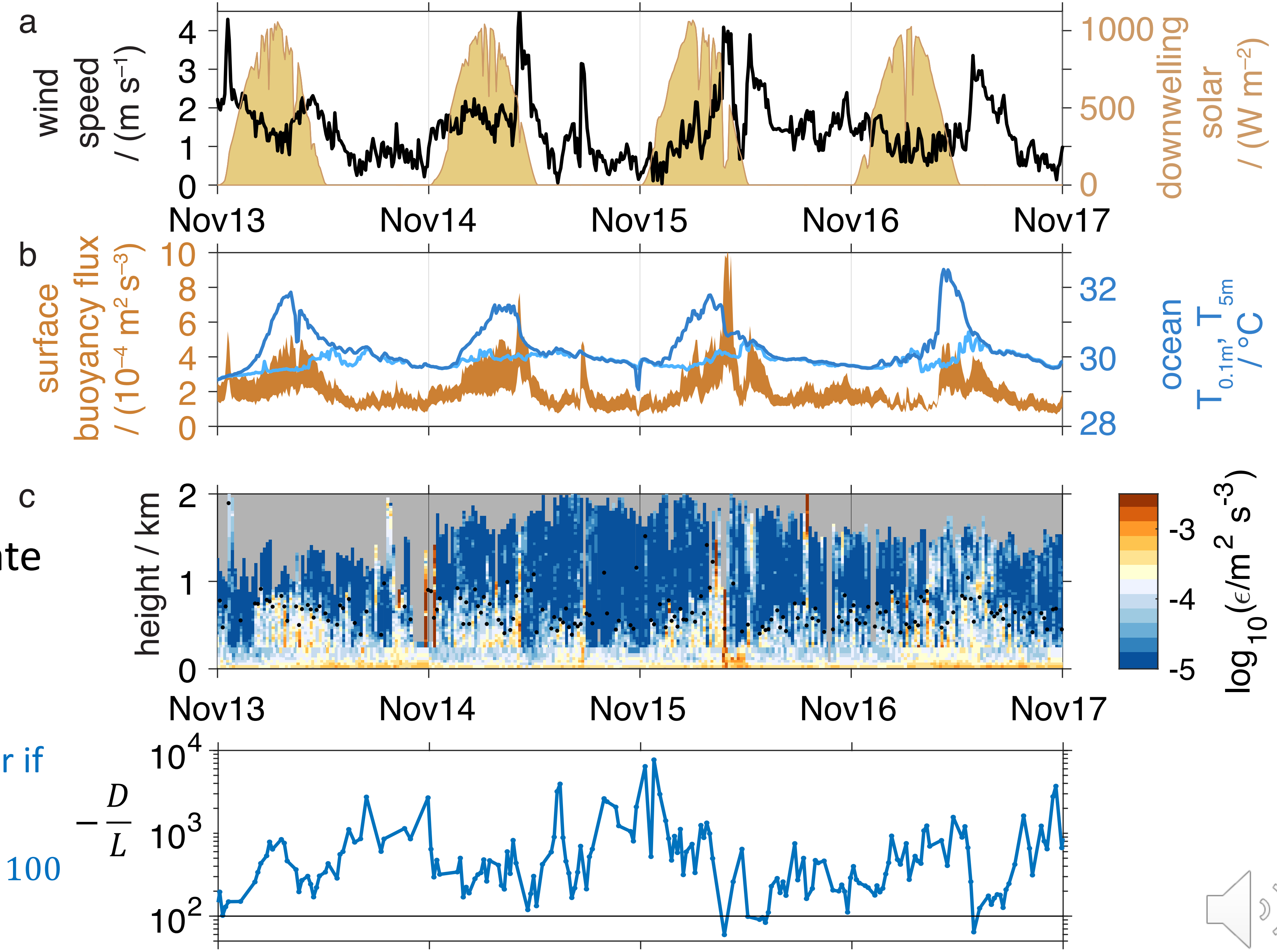
Diurnal SST days, Nov 13-17



TKE dissipation rate
(m^2 s^{-3})

Diurnal SST days, Nov 13-17

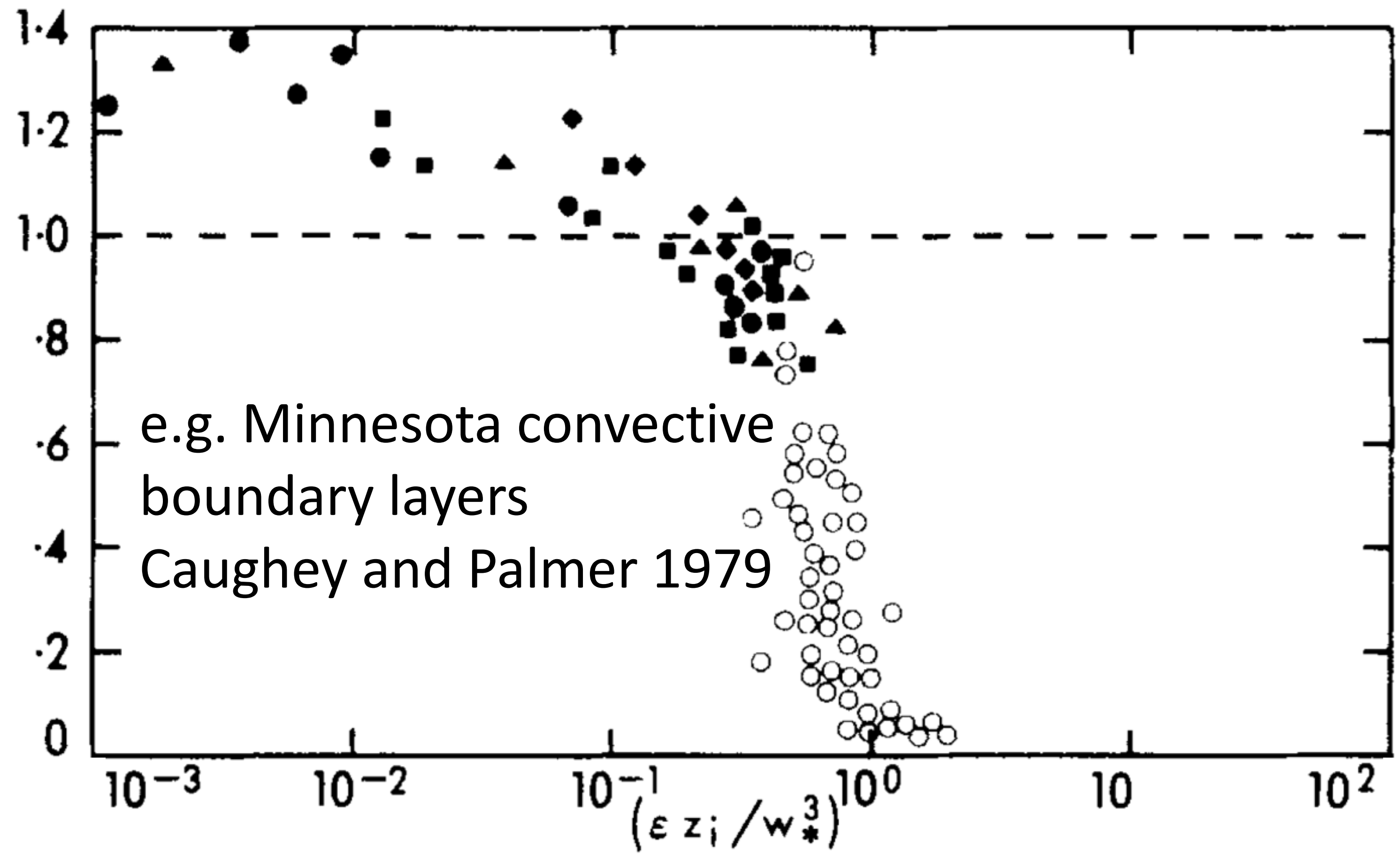
TKE dissipation rate ($m^2\ s^{-3}$)



highly convective mixed layer if

$$\frac{\text{mixed layer depth } D}{-\text{Monin–Obukhov length } L} > 100$$

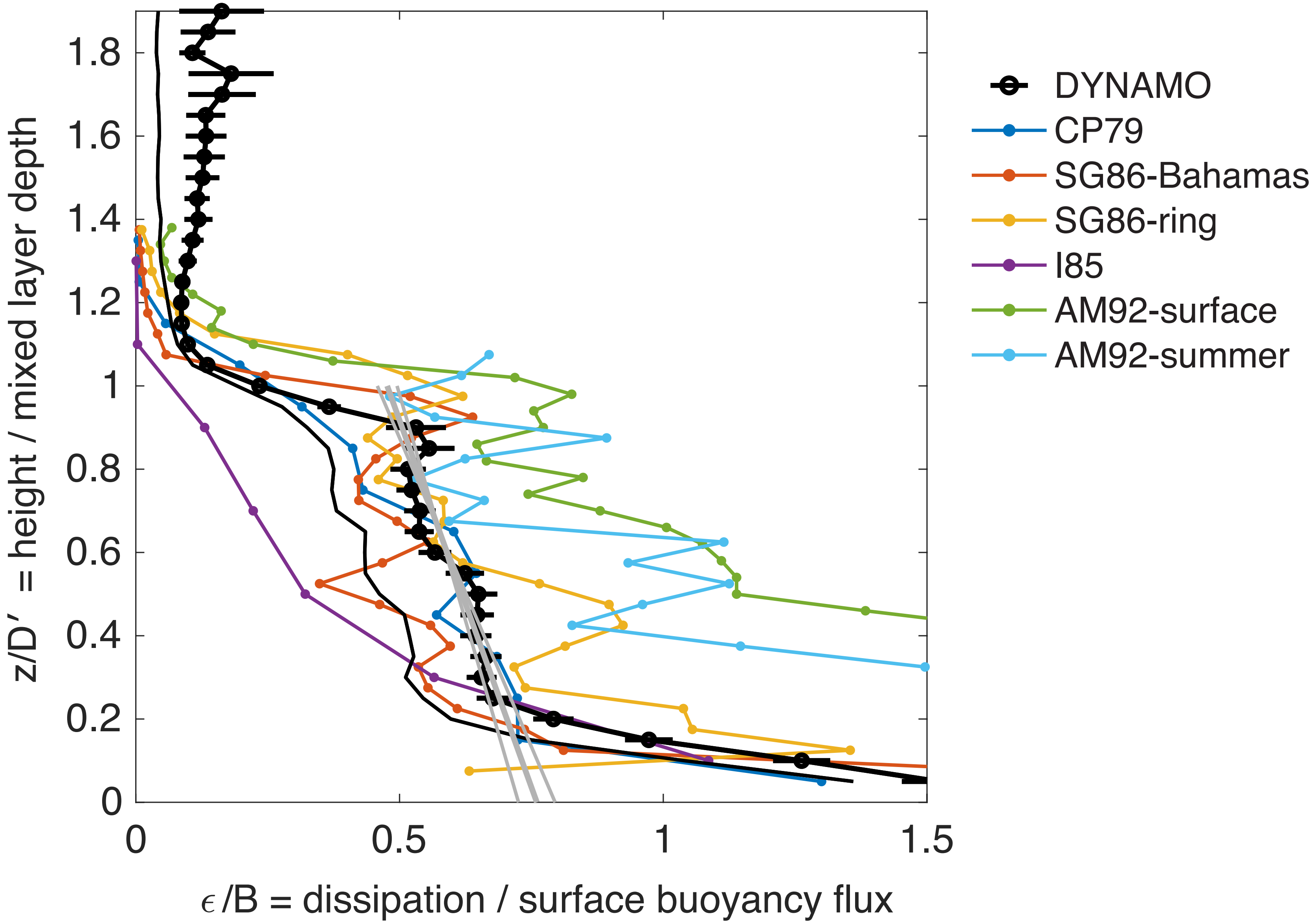
Buoyancy flux scales turbulence dissipation rate for convective mixed layers



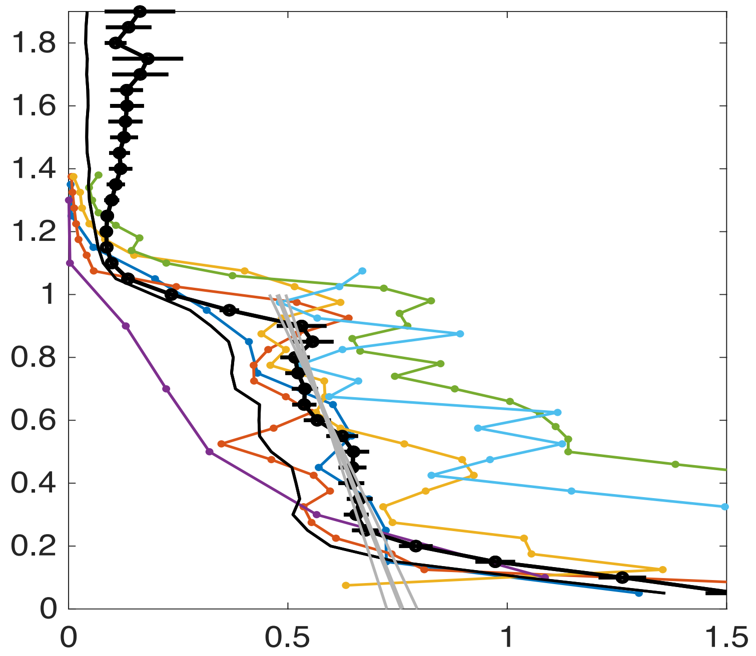
z / mixed layer depth

TKE dissipation rate / surface buoyancy flux

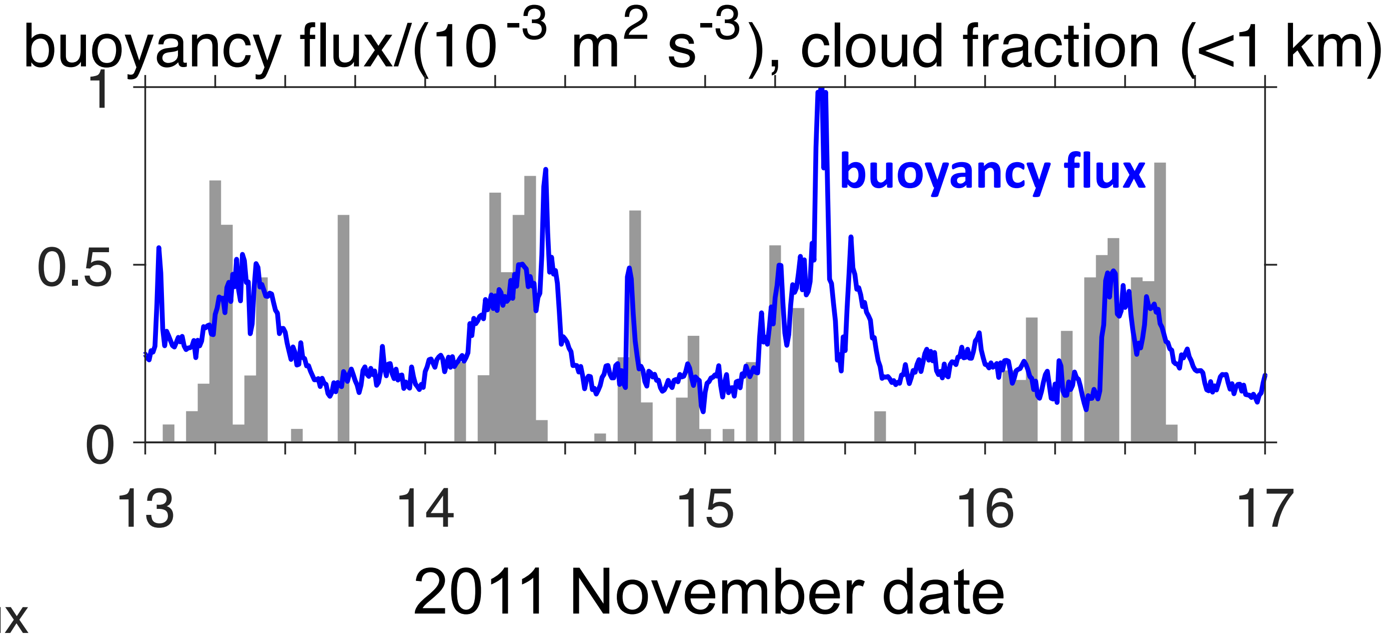
Composite scaled TKE dissipation rate



Multiply composite profile of ϵ by buoyancy flux time series
and scale by the mixed layer depth.

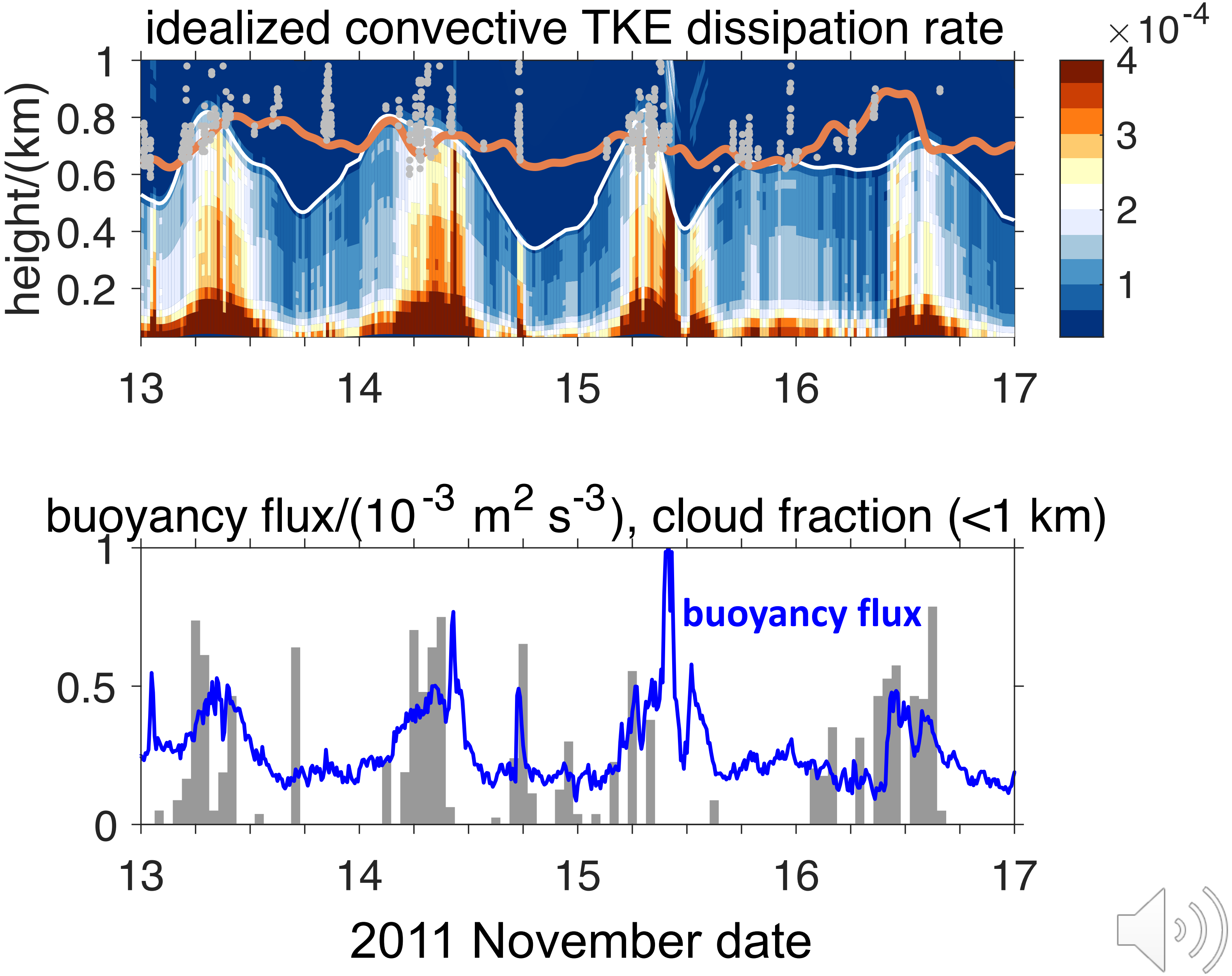


ϵ/B = dissipation / surface buoyancy flux



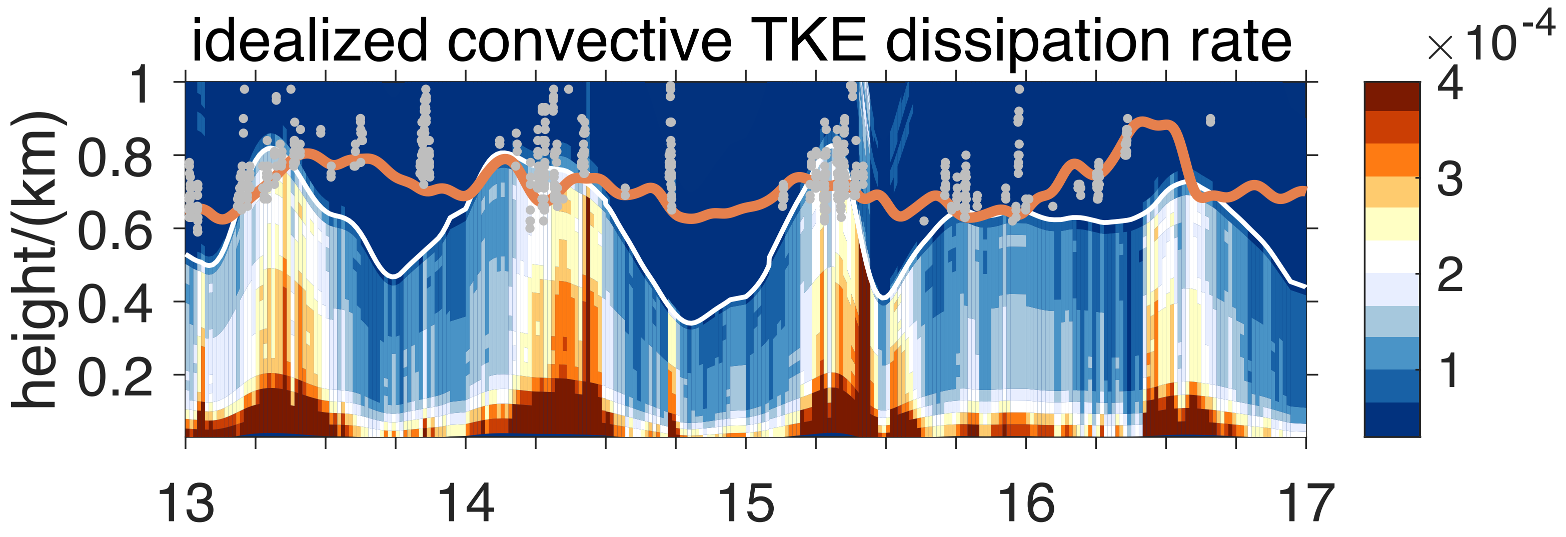
Convective mixed layer deepens in the afternoon.

Generates **clouds** at the lifting condensation level (LCL).



Summary

1. Warm afternoon SST increases buoyancy flux.
2. Turbulent kinetic energy (TKE) dissipation rate in marine convective mixed layers is proportional to surface buoyancy flux, like previous experiments.
3. Mixed layers reach the lifting condensation level and form clouds.



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de Szoeke, S. P., T. Marke, and W. A. Brewer, 2020: Diurnal ocean surface warming drives convective turbulence and clouds in the atmosphere, *Geophys. Res. Lett.* in revision https://www.essoar.org/doi/abs/10.1002/essoar.10504549.1