Mixing in the Equatorial Cold Tongues
A TAO / PIRATA Comparison of χpod Adventures

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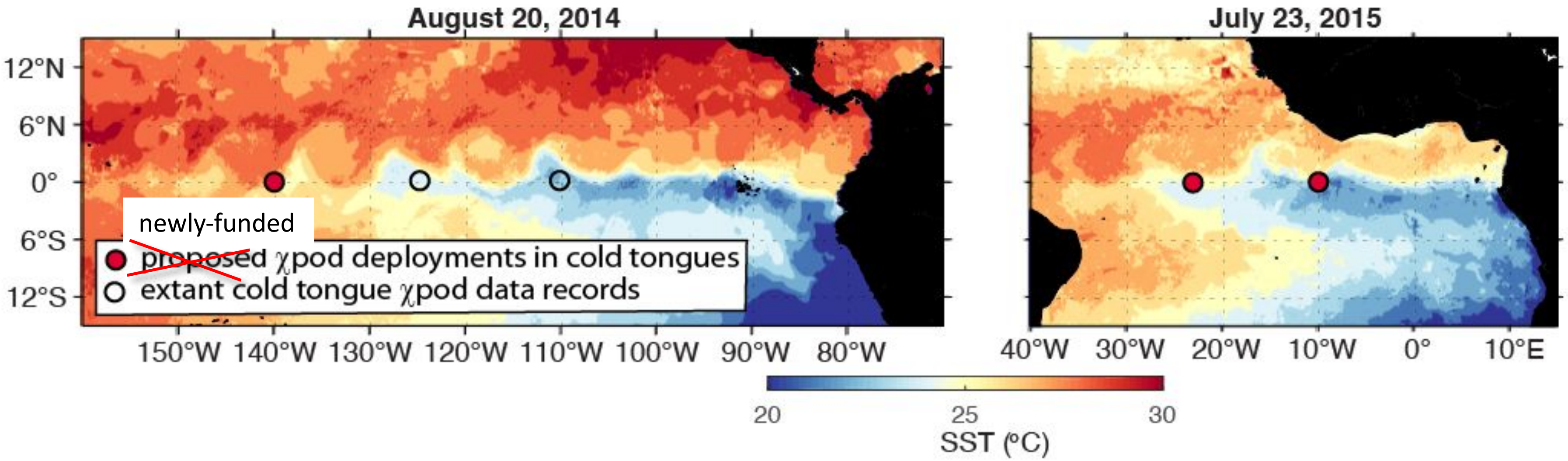
[1]*OSU* [2]*Brandeis University* [3]*IRD* [4]*GEOMAR/Kiel* [5]*NCAR*



PIRATA-24/TAV

24th Prediction and Research Moored Array in the Tropical Atlantic /Tropical Atlantic Variability Meeting

https://cpaess.ucar.edu/meetings/2021/pirata-24tav-abstract-information

Cold Tongue Mixing / NSF

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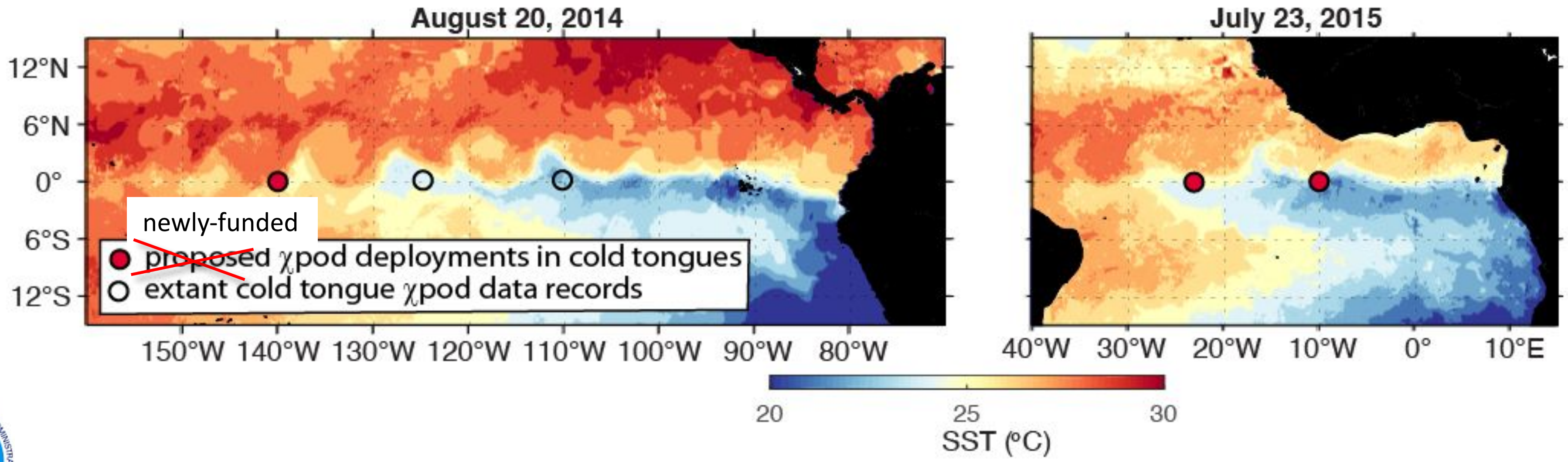
[3]Department of Marine and Environmental Sciences, Hampton University



TAO

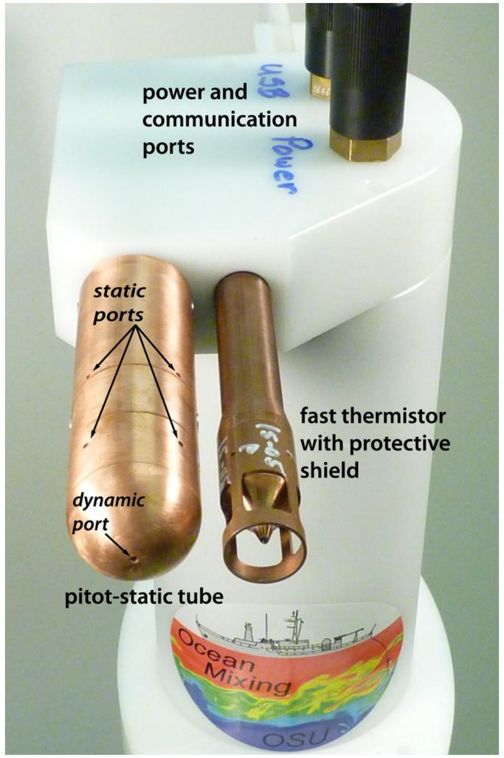
PIRATA
RAMA

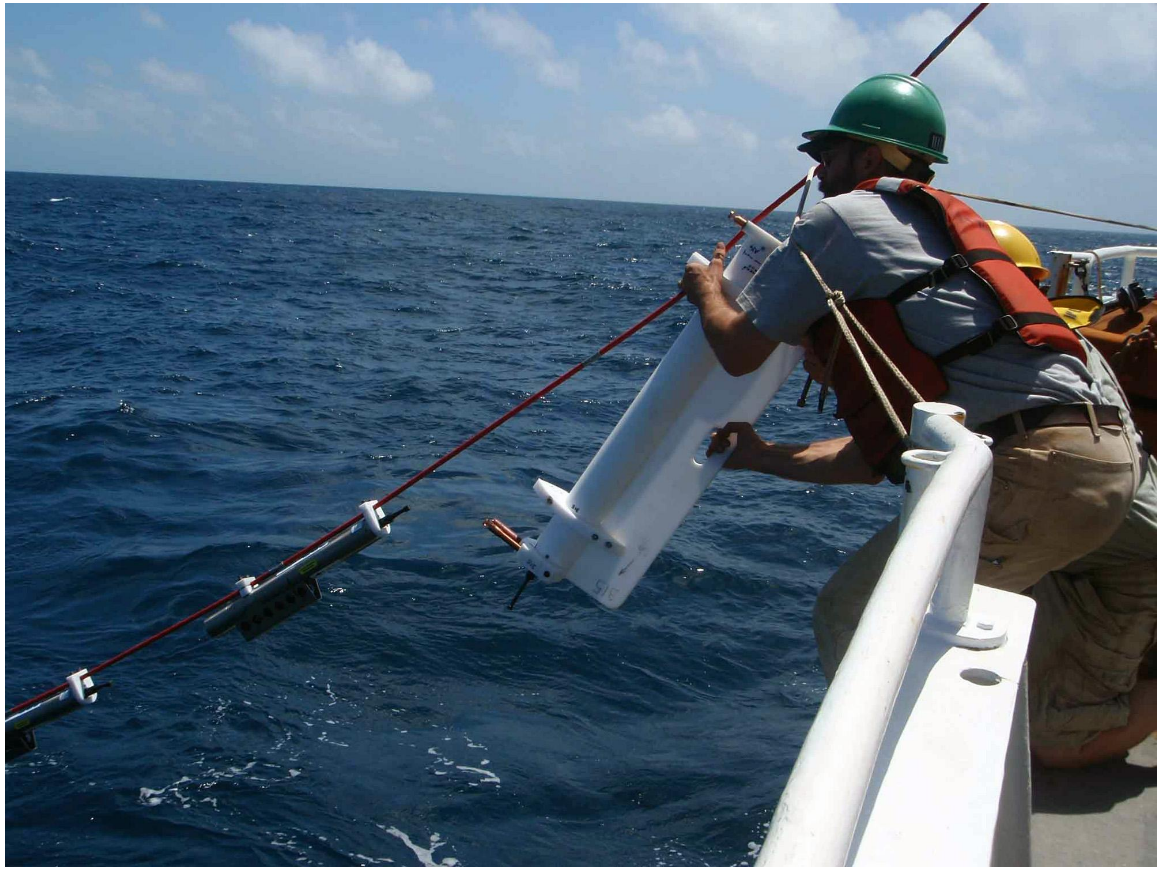
New 5y NSF grant to deploy χpods at

- **0º, 10ºW**
- **0º, 23ºW**
- **0º, 140ºW**

and to push on the analysis

χpod





<u>Technical publications define methods/processing:</u>

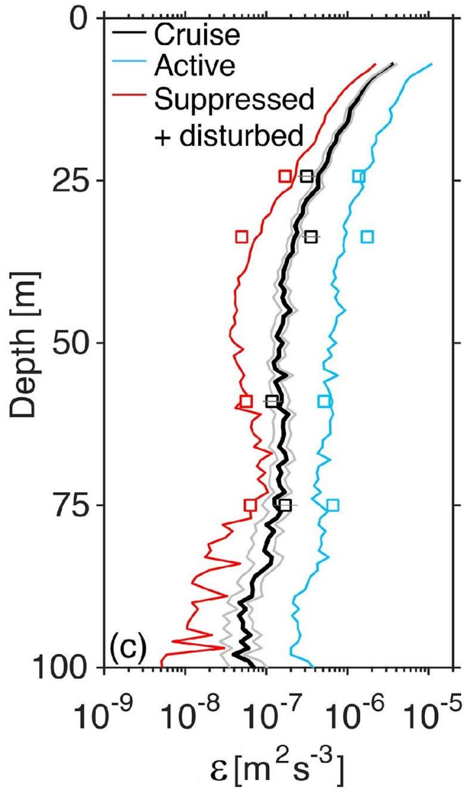
Moum & Nash, 2009 (*J. Atmos. Ocean Technol.*)
Zhang & Moum, 2010 (*J. Atmos. Ocean Technol.*)
Perlin & Moum, 2012 (*J. Atmos. Ocean Technol.*)
Moum, 2015 (*J. Atmos. Ocean Technol.*)
Becherer & Moum, 2017 (*J. Atmos. Ocean Technol.*)

Ocean Mixing OSU

How we know χpods work

<u>0, 80 E / 2011 DYNAMO</u>

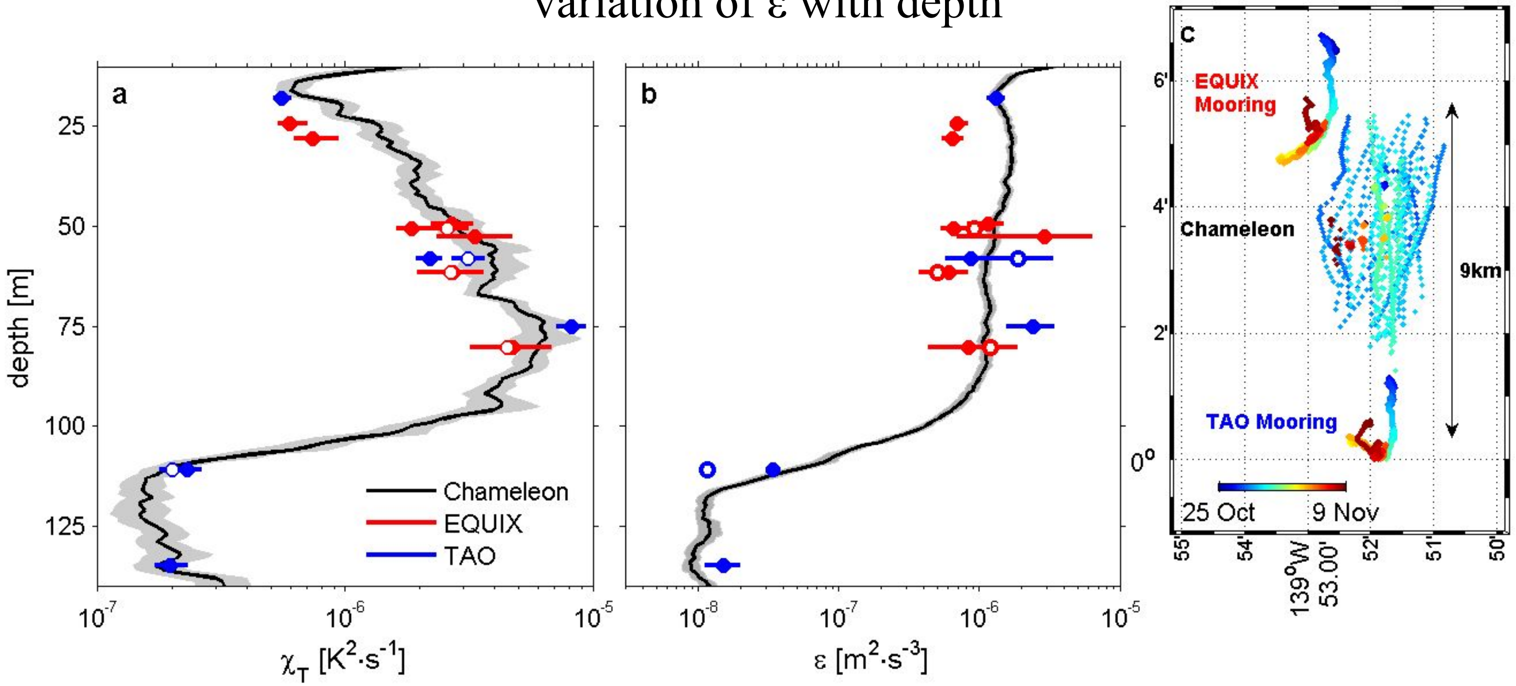
variation of ε with MJO phase



Pujiana etal 2018 (*JPO*)

<u>0, 140W / boreal autumn 2008</u>

variation of ε with depth



Perlin & Moum, 2012 (*J. Atmos. Ocean Technol.*)

comparison of χ, ε from χpods on moorings with turbulence profiling on shipboard field experiments

turbulence profiler *Chameleon* → ε from shear probes

moored *χpods* → ε_χ inferred from $N^2\chi/(2\Gamma T_z^2)$

Objective: quantify the role of mixing of energy, heat and momentum on Cold Tongue Dynamics

To this end we derive from these measurements

1. turbulence diffusivities for heat and momentum, K_t and K_m ← these are sort of what modelers think they need

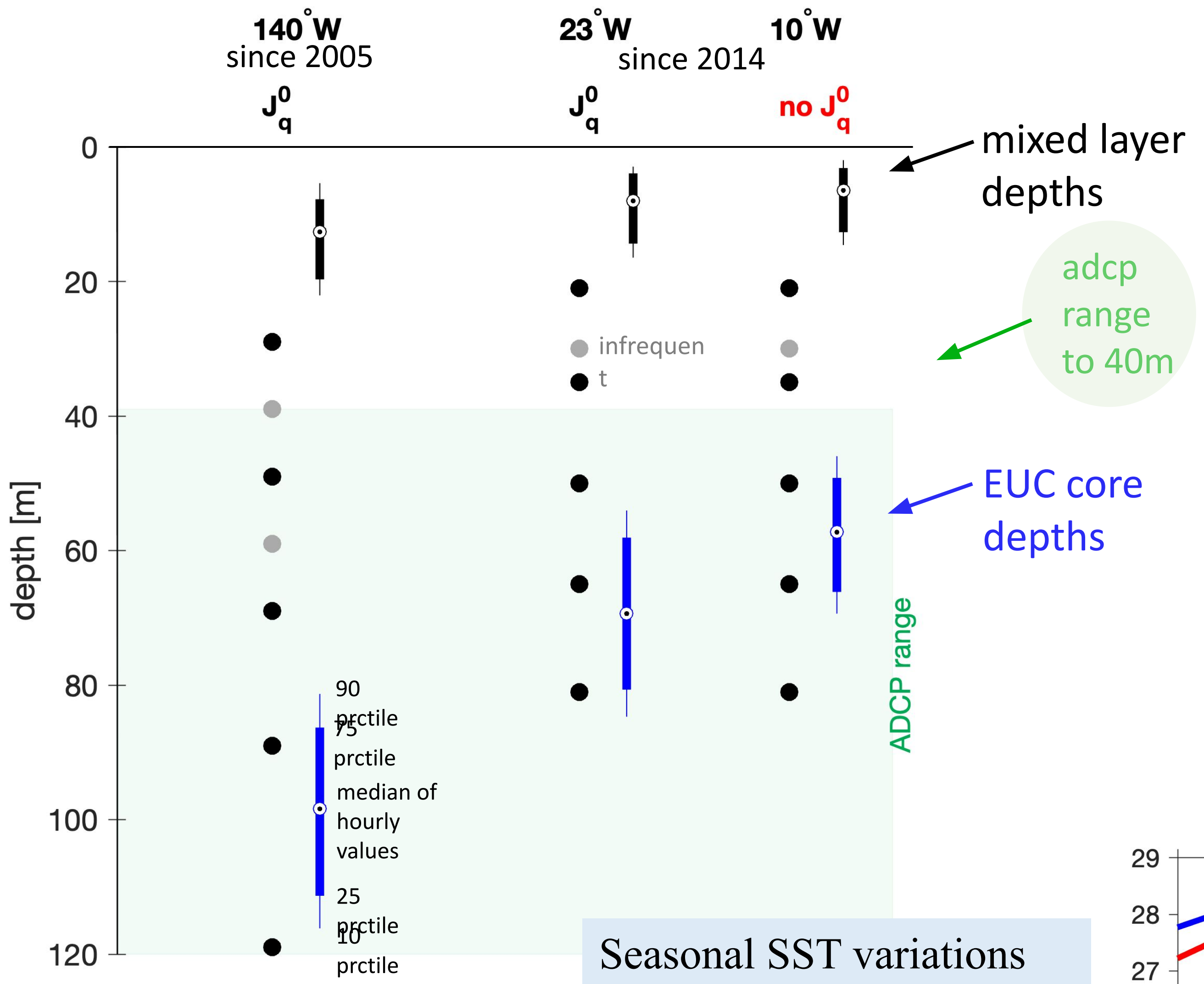
2. turbulence dissipation rates, ε

3. turbulence heat flux, J_q^t

4. turbulence momentum flux, J_m^t

← these are rate variables that appear in equations governing rates of change of energy, heat and momentum

these tell us what the state variables ***will*** be



important *commonalities* of the 3 sites

- EUC
- highly-sheared near surface flows
- Ri ≅ 1/4 over MLD to EUC / marginal instability (MI)

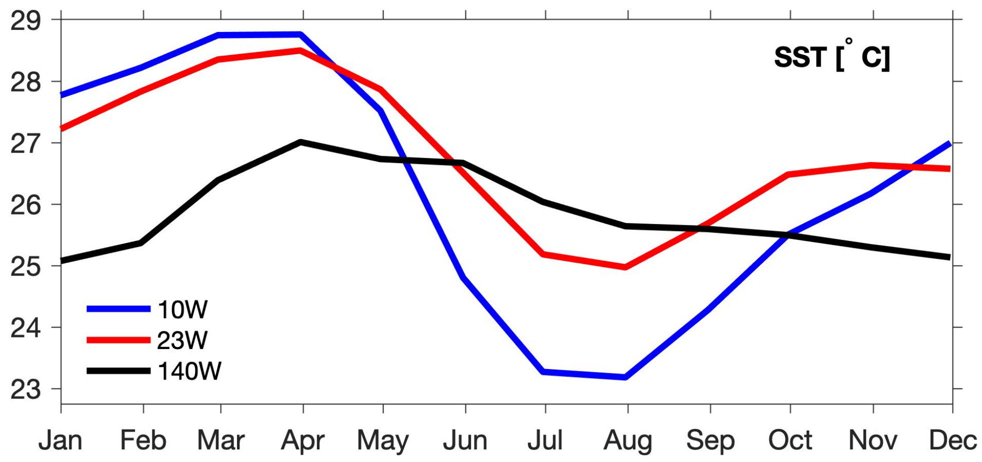
important *distinctions* between the 3 sites

~~at 0~~, 140W

- windier
- greater TIW KE
- deeper ML, EUC
- thicker MI layer

Seasonal SST variations

0, 140W	2°C
0, 23W	>3°C
0, 10W	>5°C



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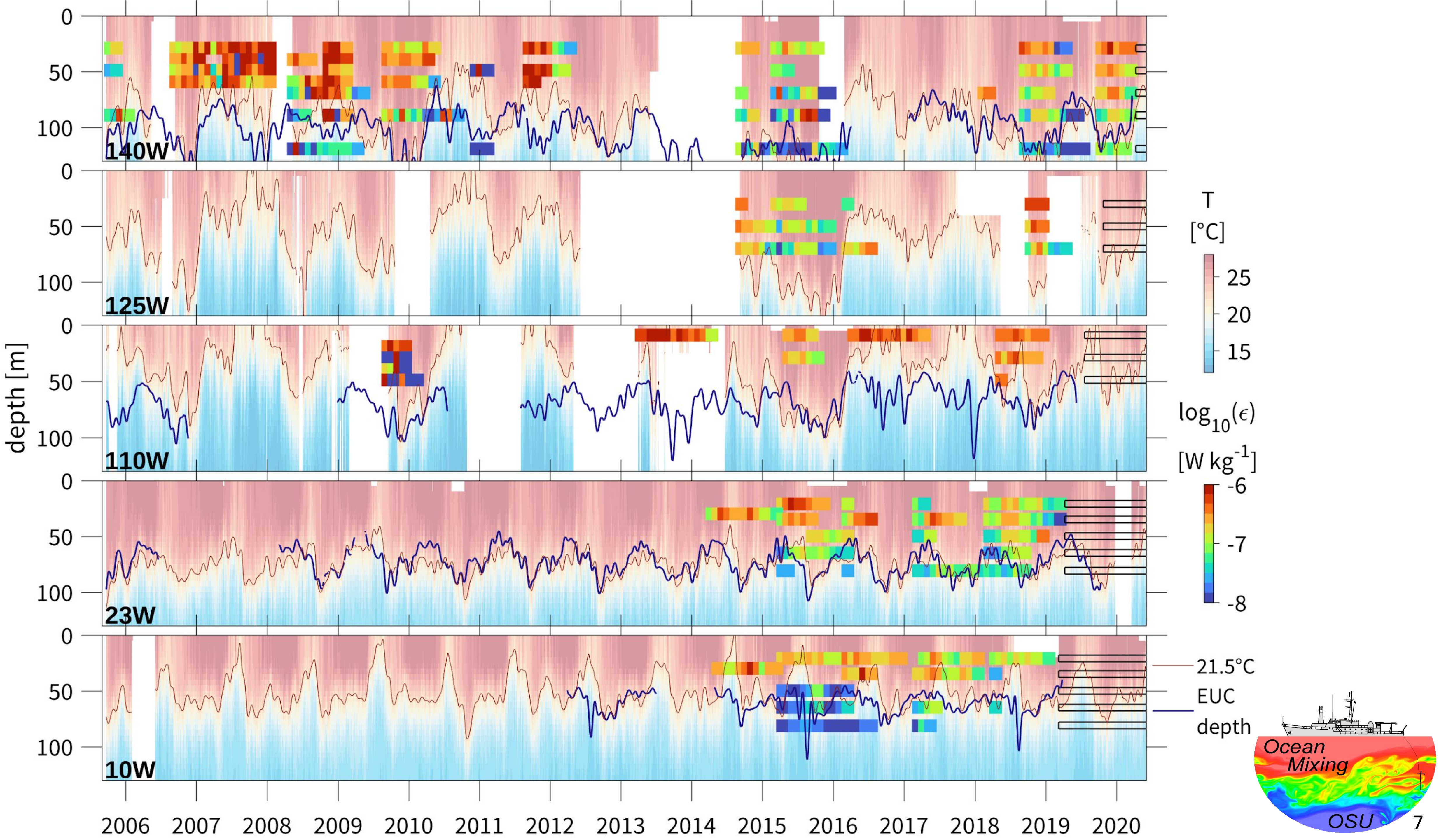


depth [m]
140W
125W
110W
23W
10W
0
50
100
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
T
[°C]
25
20
15
$\log_{10}(\epsilon)$
[W kg^{-1}]
-6
-7
-8
21.5°C
EUC
depth
Ocean
Mixing
OSU

Combined shipboard and moored χpod measurements at 0, 140W have shown:

- diurnal deep cycle (below the mixed layer) of mixing / Moum etal 1989 (*JGR*); Lien etal, 1995 (*JGR*)
- marginal instability ($Ri \cong 1/4$) between MLD and EUC core / Smyth & Moum 2013 (*GRL*)
- descent rate of deep cycle (in S^2, N^2, ε) / Smyth etal, 2013 (*JPO*)
- seasonal variability of turbulence and heating that accounts for seasonal SST changes / Moum etal 2013 (*Nature*)
- feedbacks to ENSO phase change / Warner & Moum, 2019 (*GRL*)

today, we compare χpod measurements

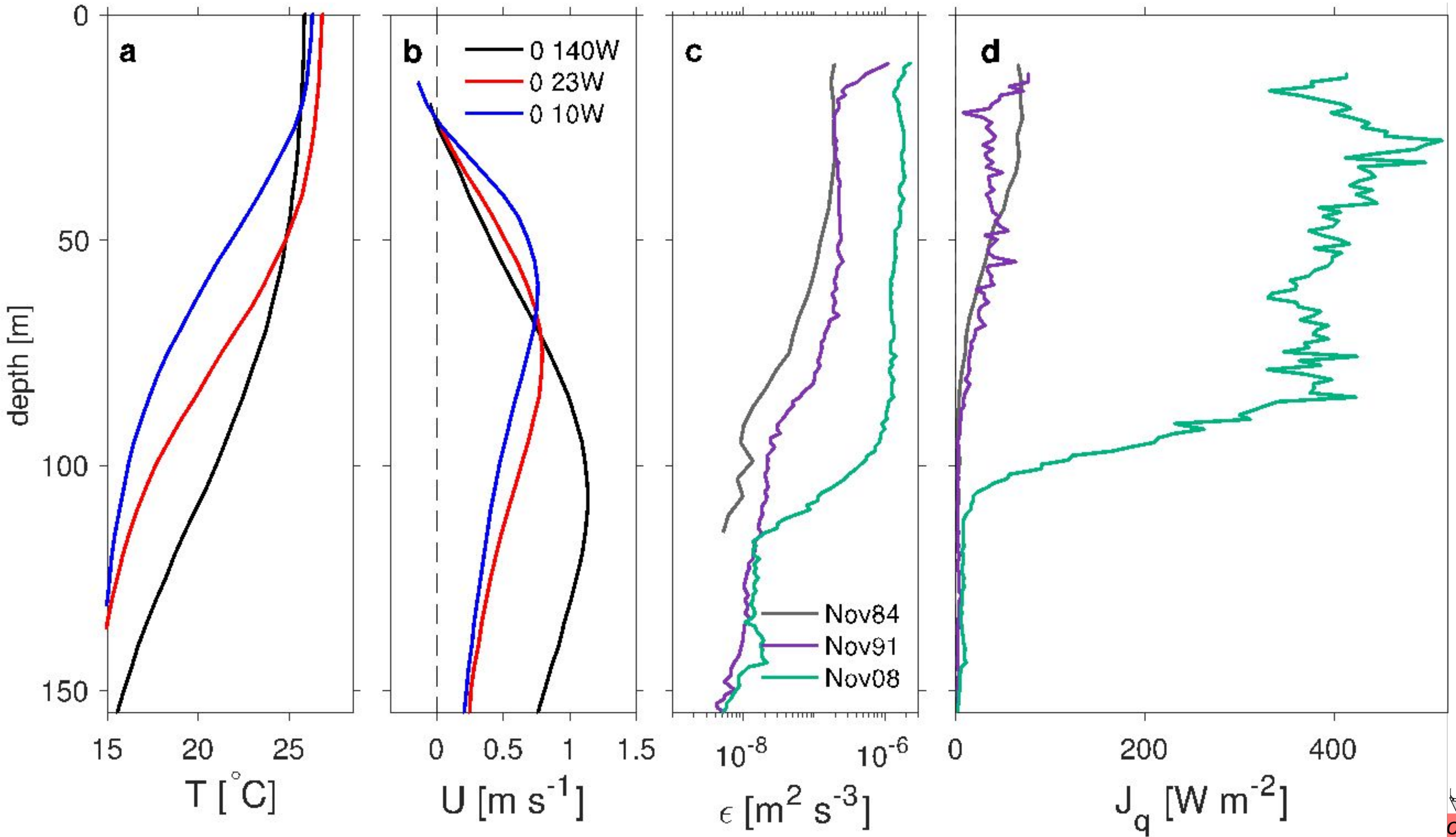
PCT (0, 140W)

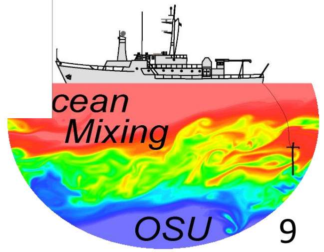
ACT (0, 10W; 0, 23W)

- *Averaged vertical profiles*
- *Diurnal variability of mixing*
- *Seasonal variability of turbulence and heating*

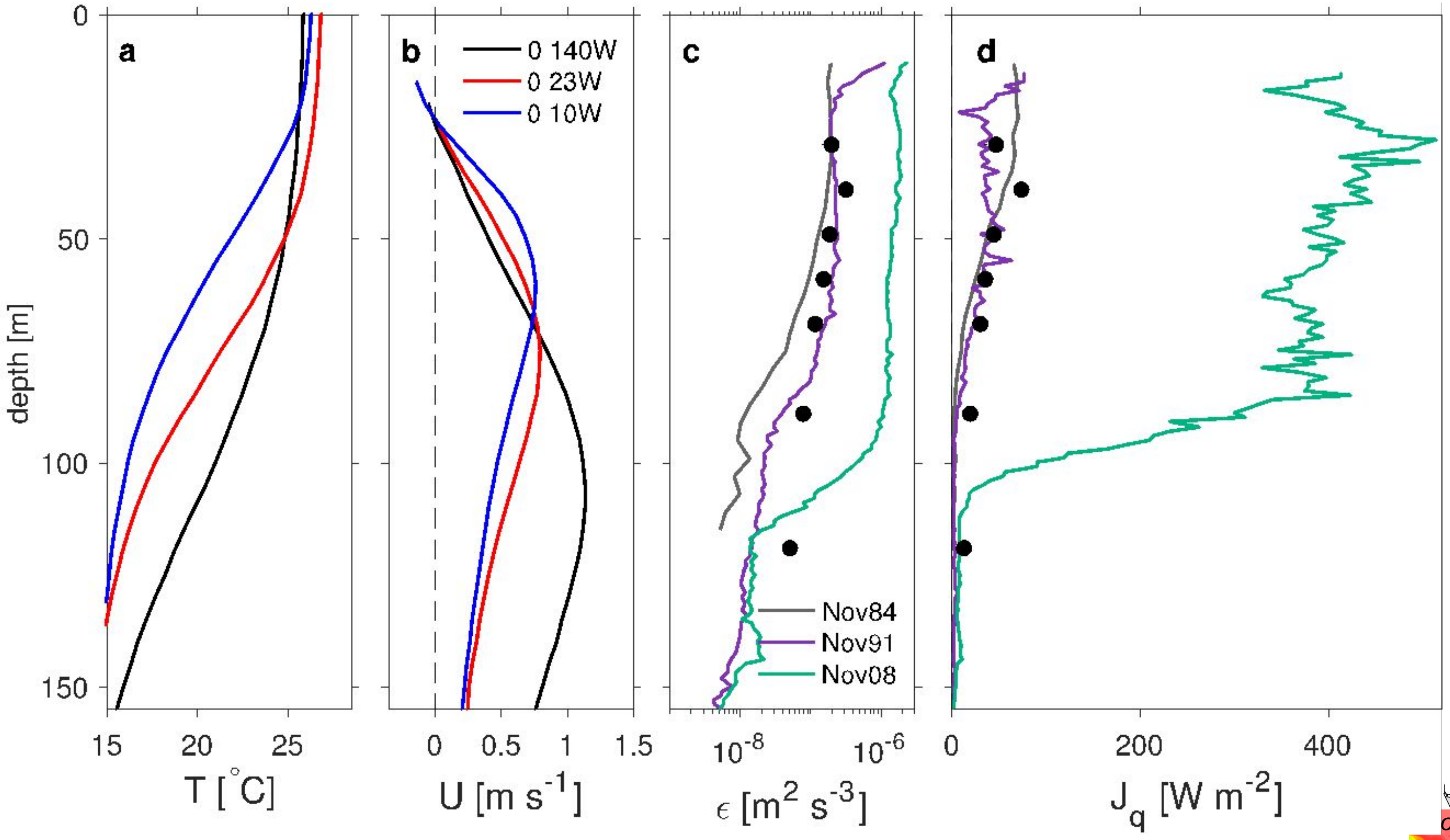
Averaged vertical profiles (2014-2019)

results from turbulence profiling experiments at 0 140W

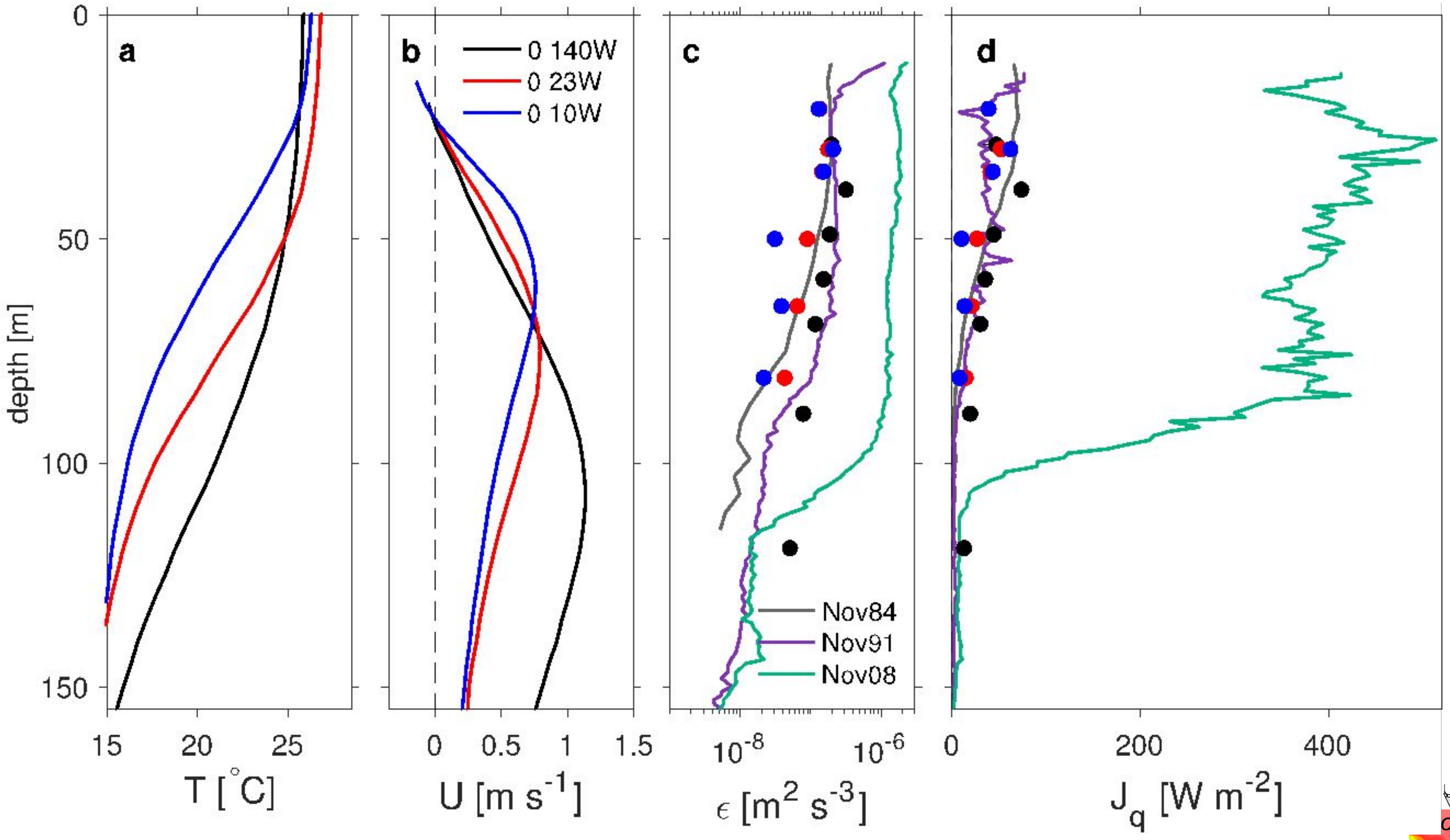


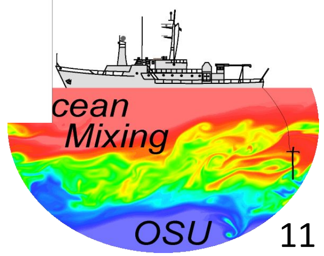


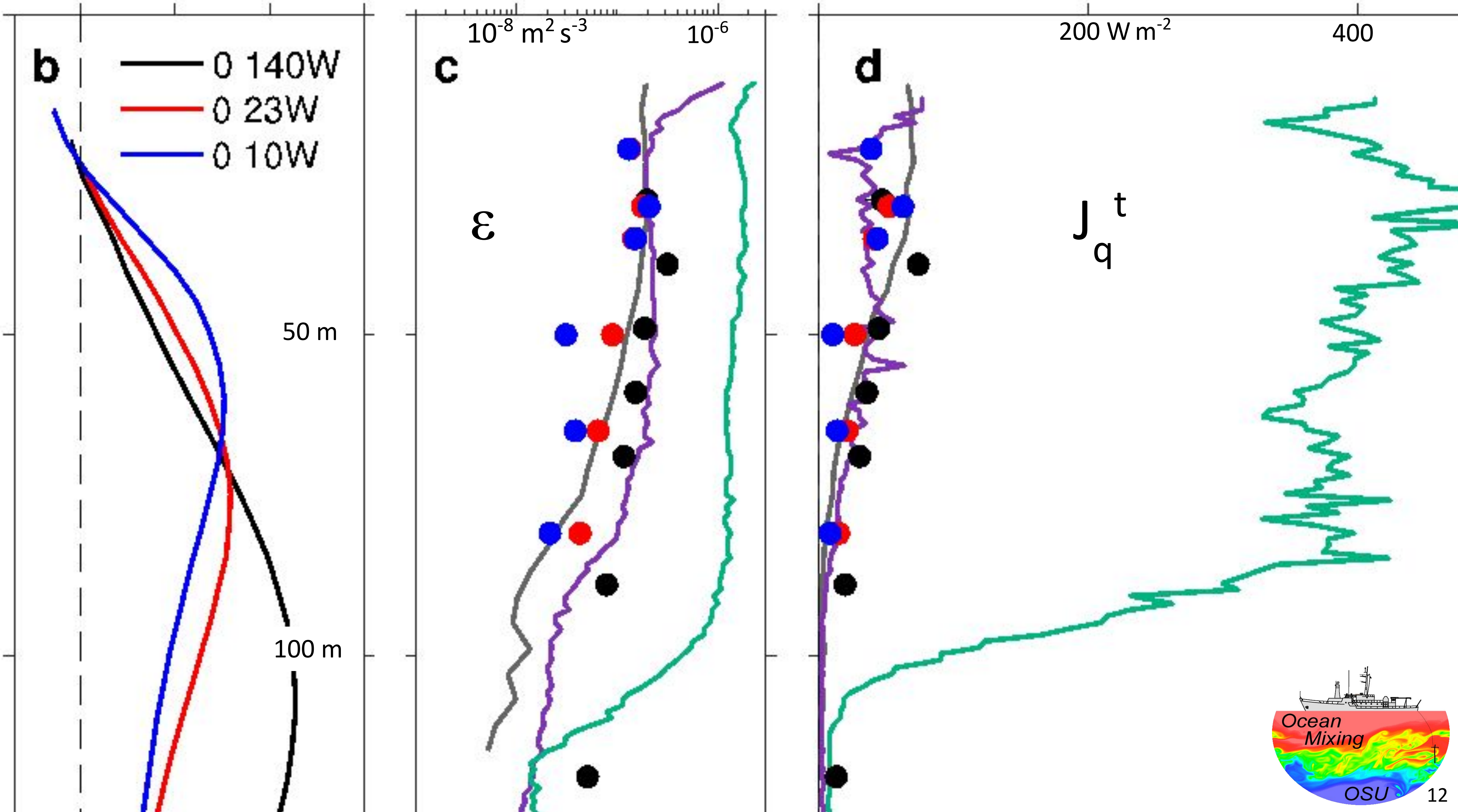
add full 0,140W χpod record (2005-2019)



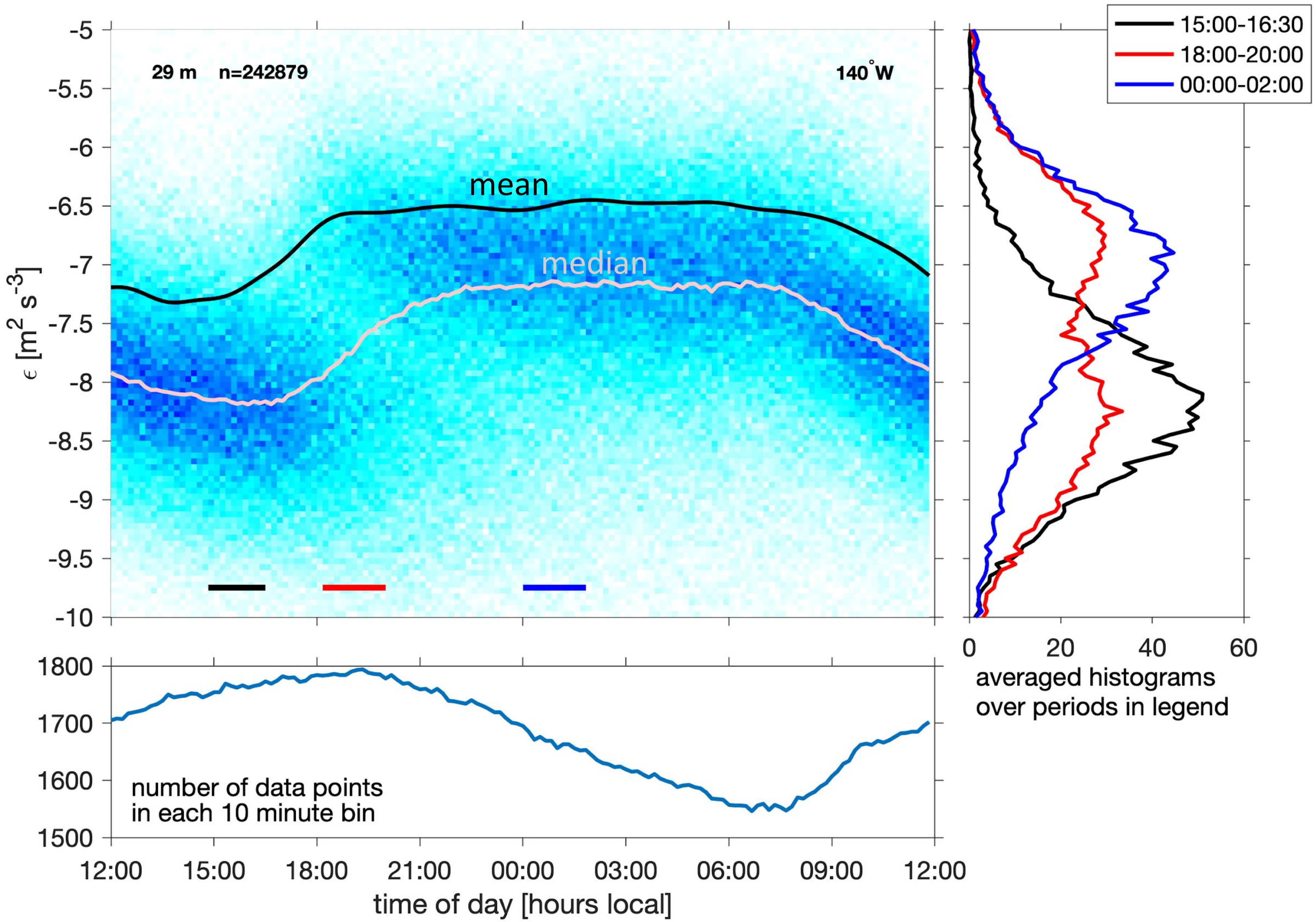
add 0,10W and 0,23W χpod records



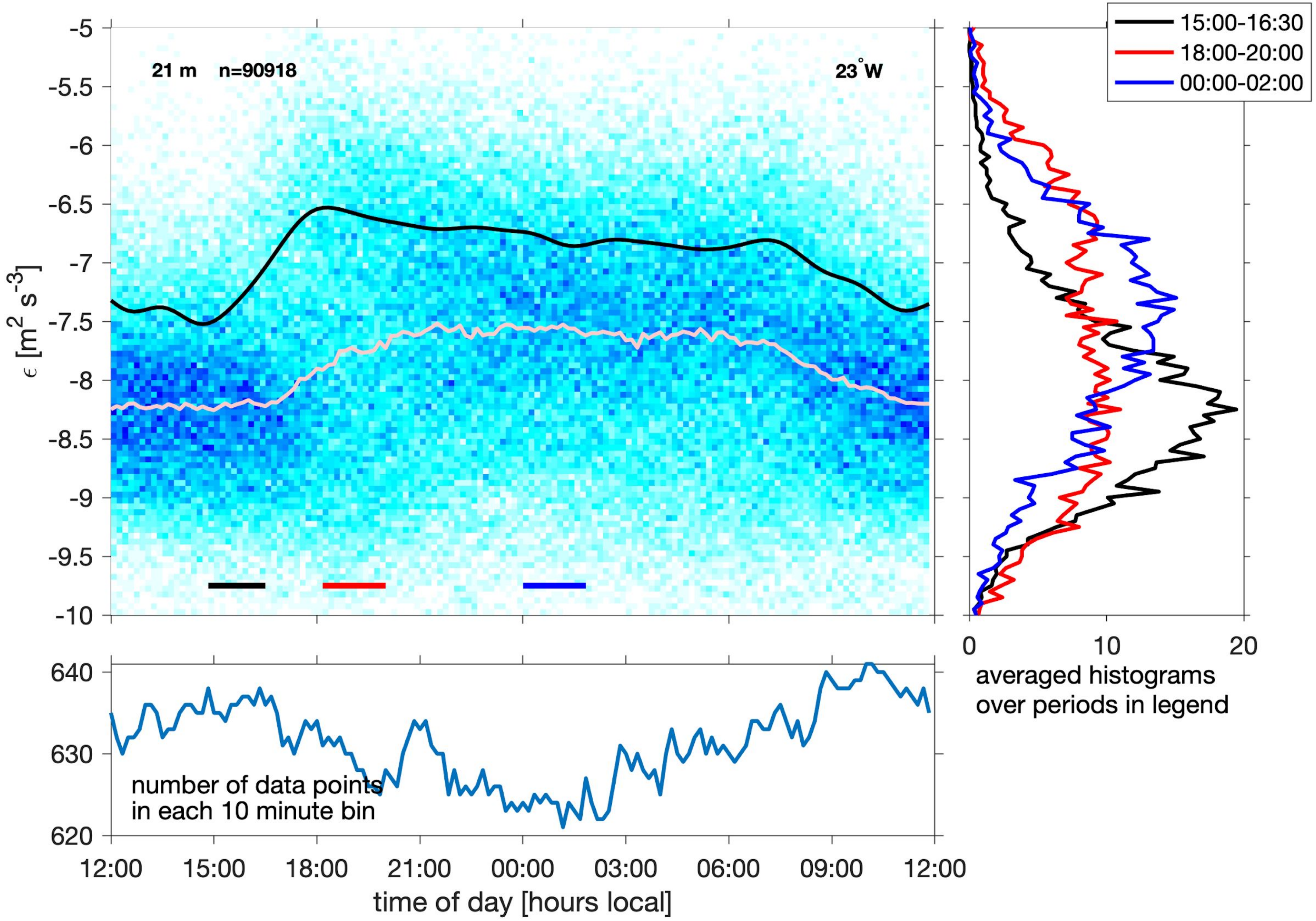



b
0 140W
0 23W
0 10W
50 m
100 m
c
10^{-8} m^2 s^{-3}
10^{-6}
ε
d
200 W m^{-2}
400
J_q^t

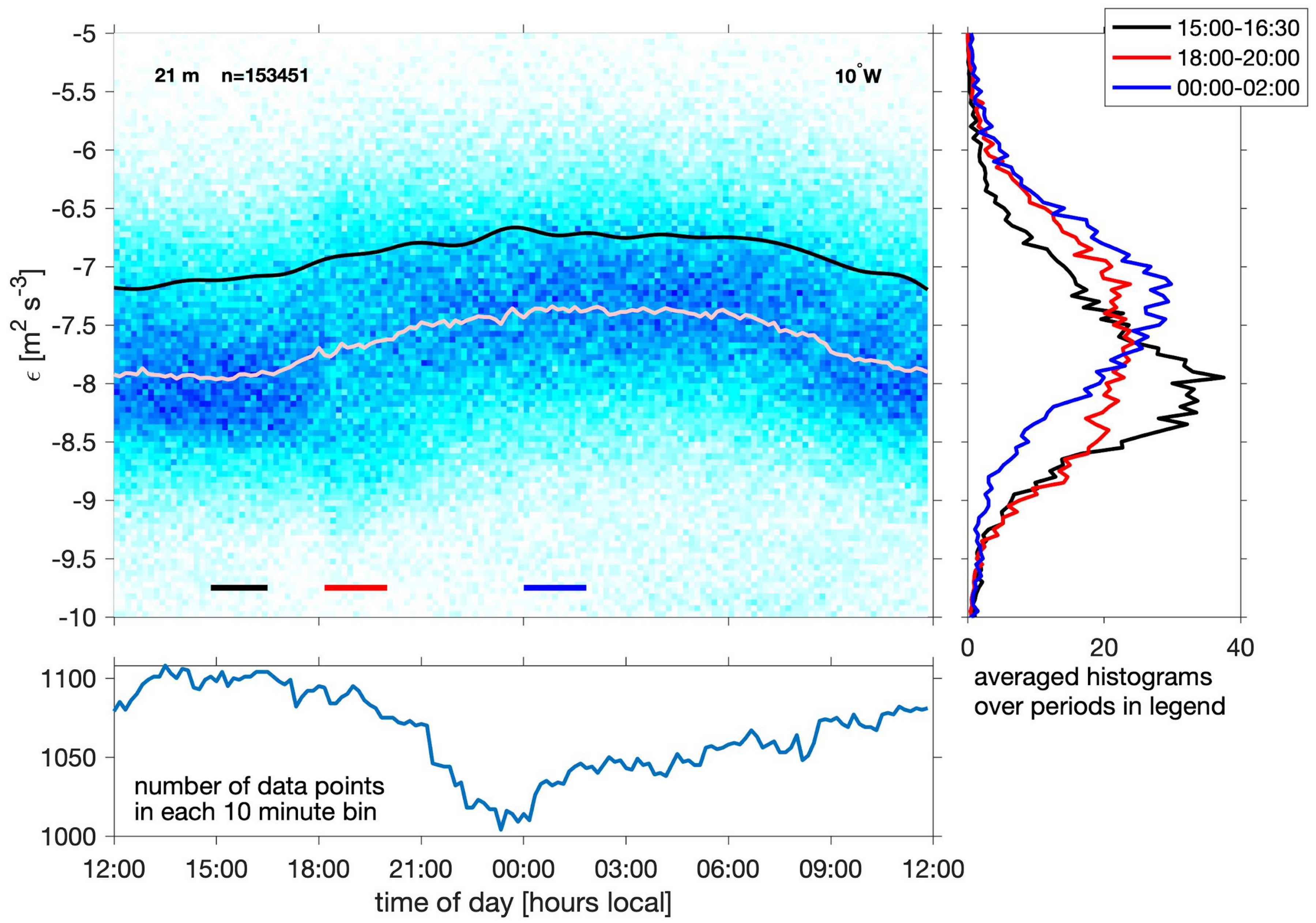
Diurnal variability of mixing



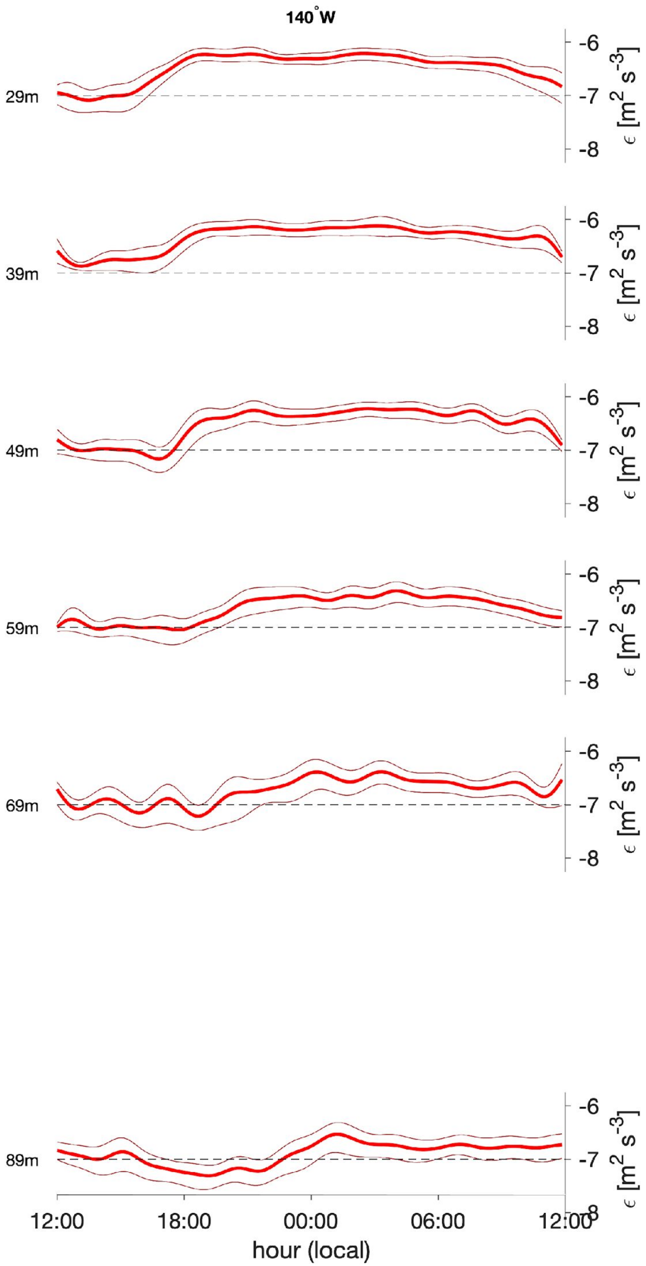
Ocean Mixing OSU



Ocean Mixing OSU

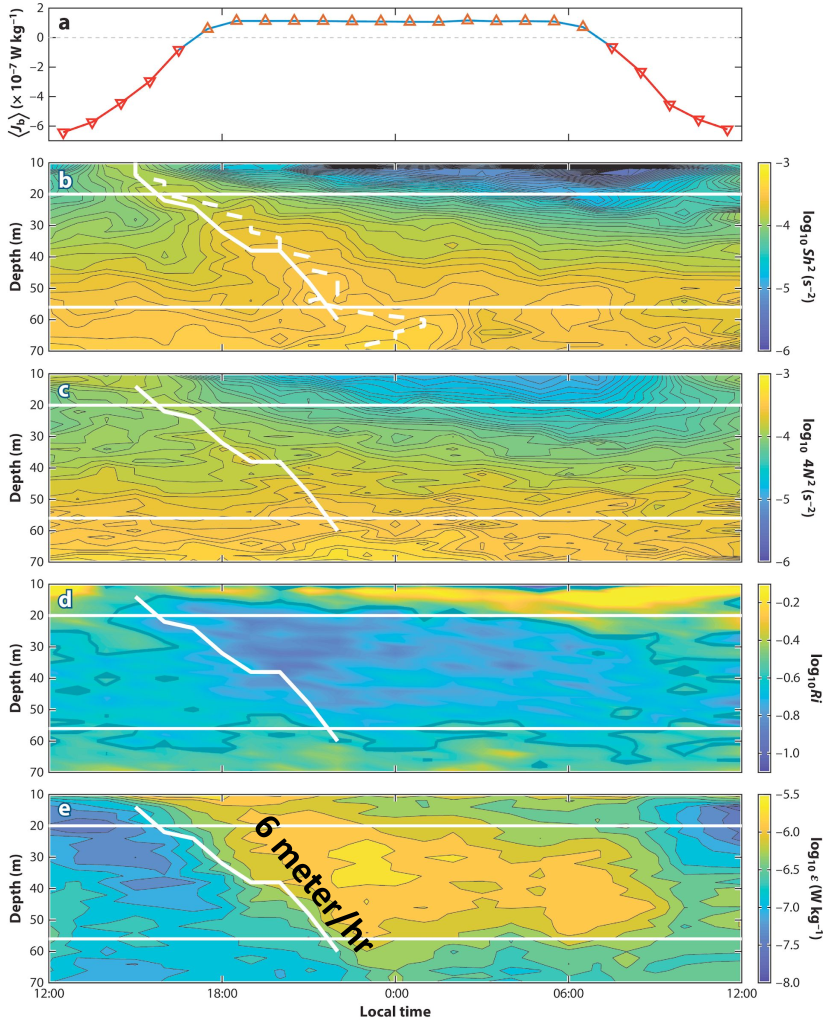

21 m n=153451
10°W
15:00-16:30
18:00-20:00
00:00-02:00
ϵ [m^2 s^{-3}]
averaged histograms
over periods in legend
number of data points
in each 10 minute bin
time of day [hours local]

τ > 0.075 Pa


140°W
29m
39m
49m
59m
69m
89m
-6
-7
-8
ϵ [m² s⁻³]
12:00
18:00
00:00
06:00
12:00
hour (local)

τ > 0.075 Pa

diurnal descent of S^2, N^2, ε layers

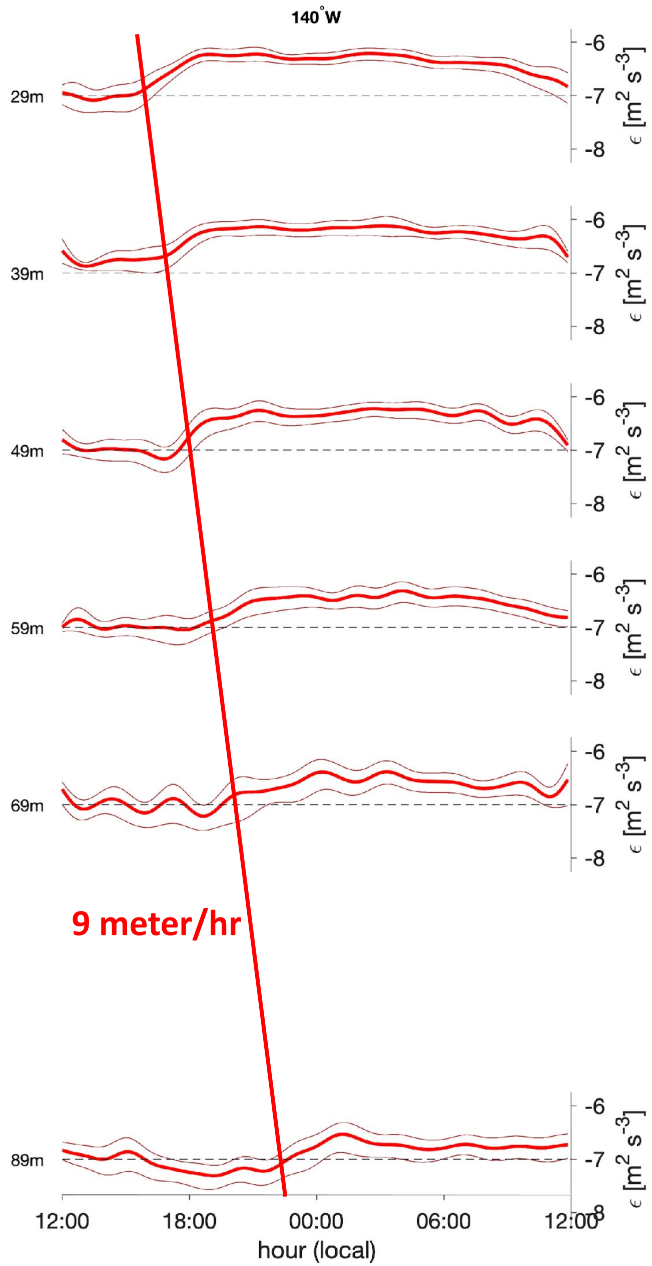


Moum JN. 2021
Annu. Rev. Mar. Sci. 13:201–26

Smyth etal, 2013 (*JPO*)

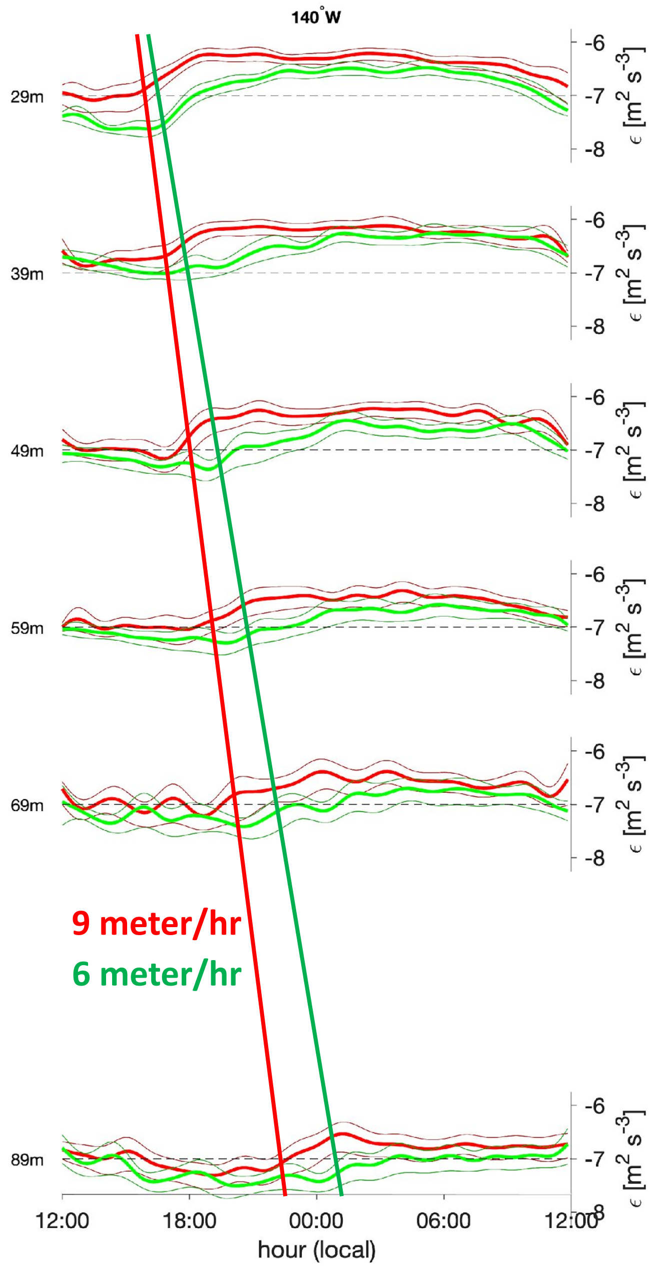
computed from 8 day record

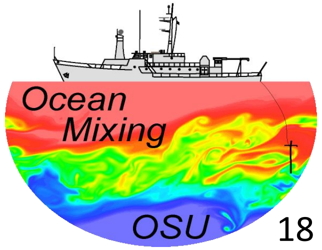
computed from 15 year record



$\tau > 0.075$ Pa

0.04 Pa $< \tau < 0.075$ Pa

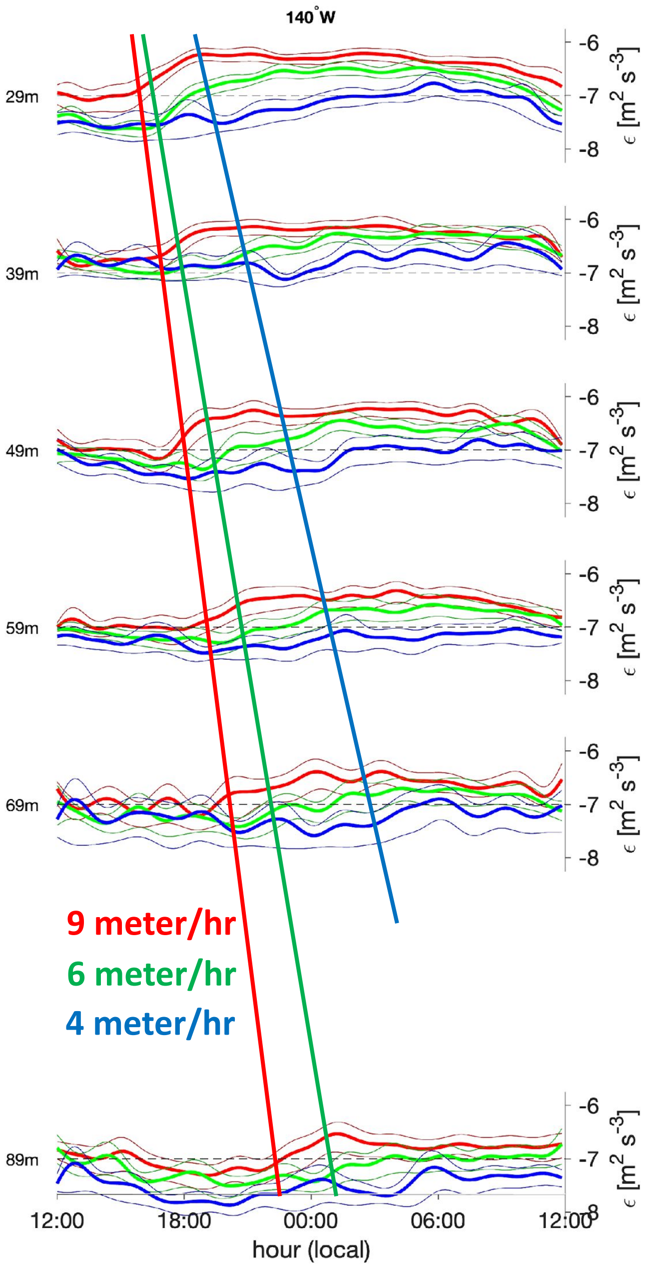




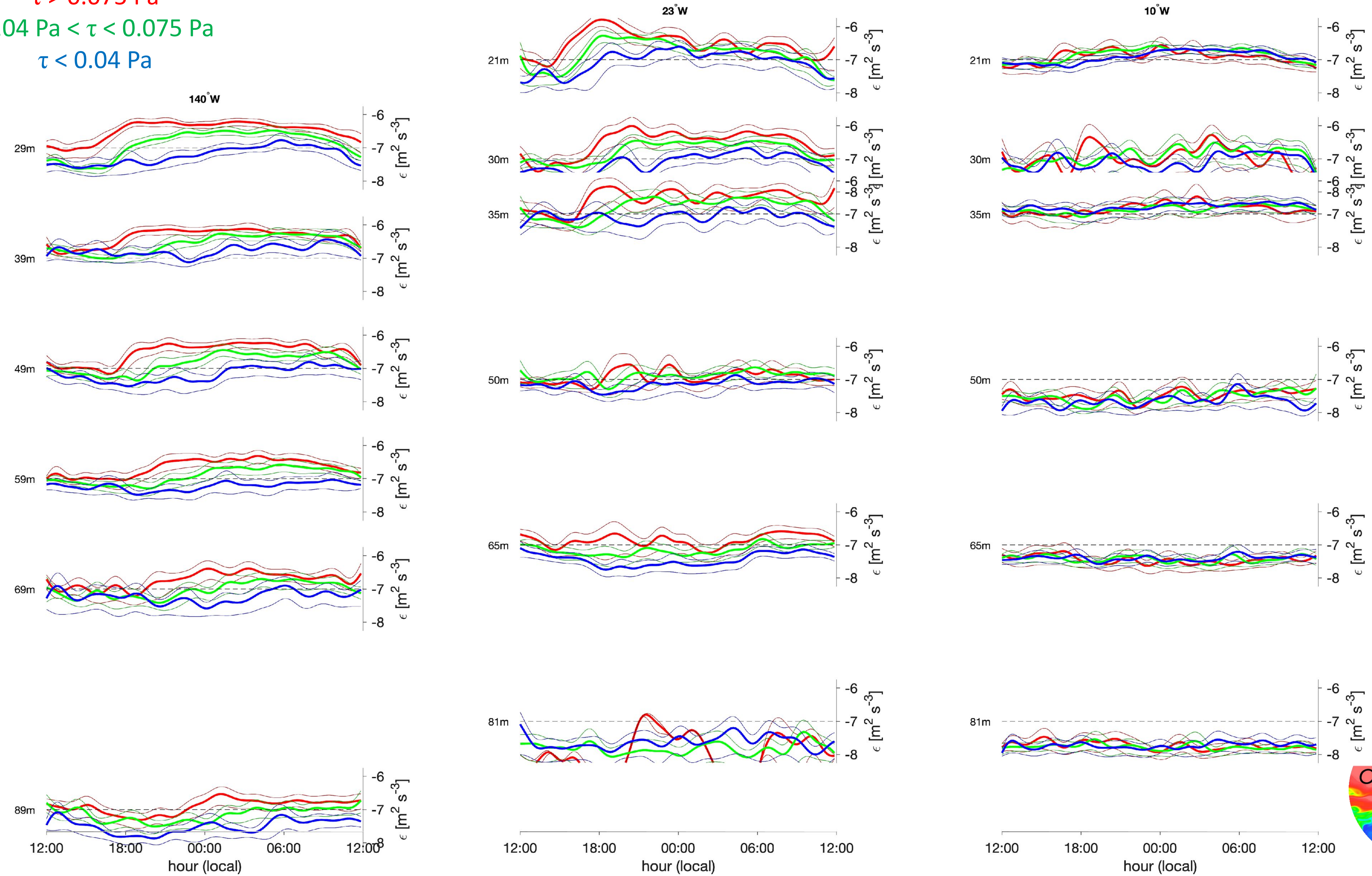
$\tau > 0.075$ Pa

0.04 Pa $< \tau <$ 0.075 Pa

$\tau <$ 0.04 Pa



τ > 0.075 Pa
0.04 Pa < τ < 0.075 Pa
τ < 0.04 Pa



Seasonal variability of turbulence and heating

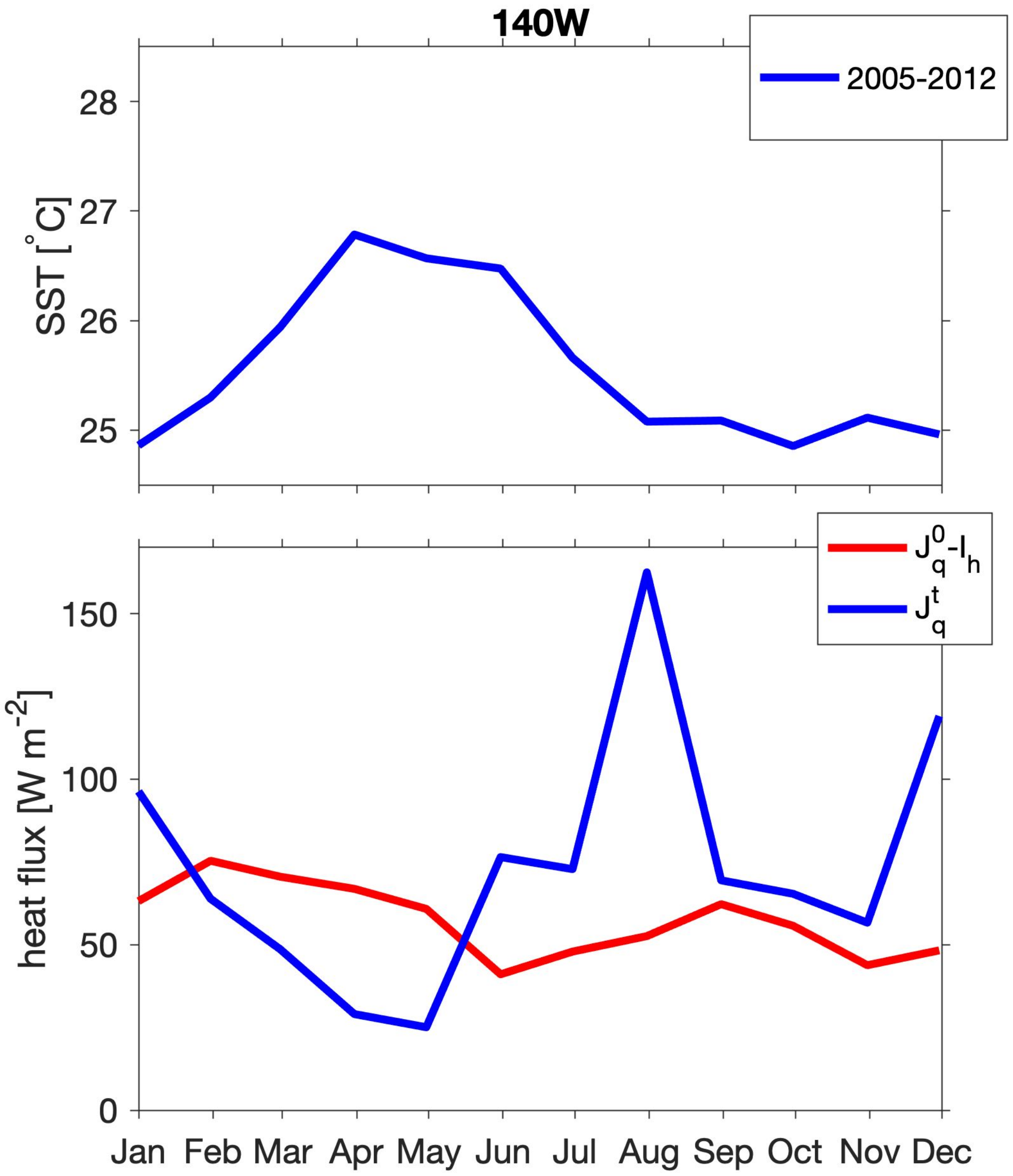
$$\frac{\partial T_{mld}}{\partial t} = \frac{1}{\rho C_p}\frac{\partial J_q}{\partial z}$$

$$\approx \frac{1}{\rho C_p}(J_q^0 - I_h - J_q^t)/h$$

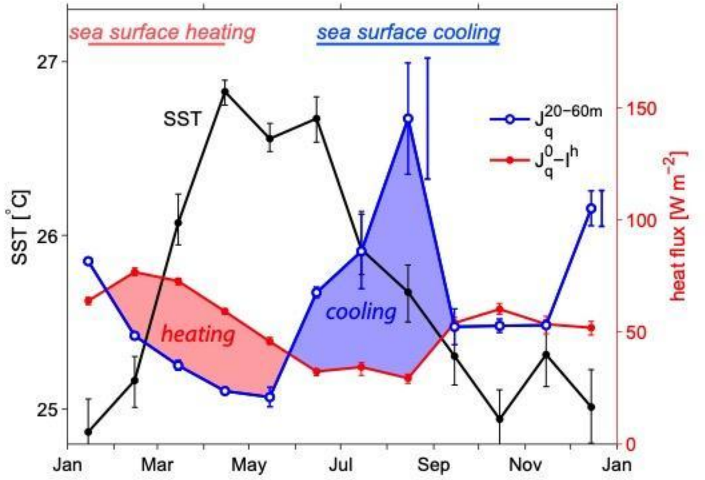
J_q^0 - net surface heat flux

I_h - short wave penetration through mixed layer base h

J_q^t - turbulent heat flux at h



Seasonal sea surface cooling in the equatorial Pacific cold tongue controlled by ocean mixing



Moum etal, 2013 (*Nature*)

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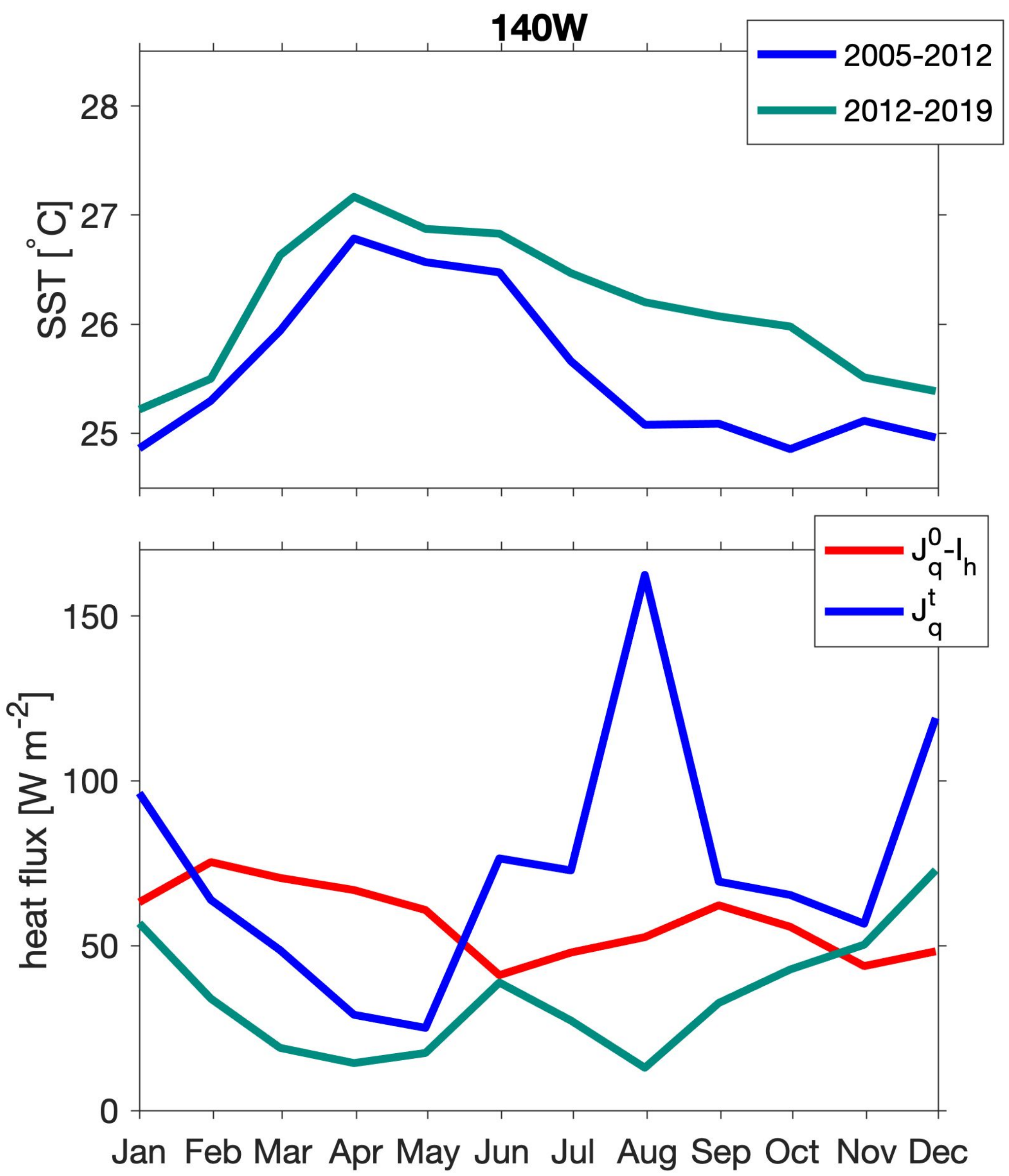

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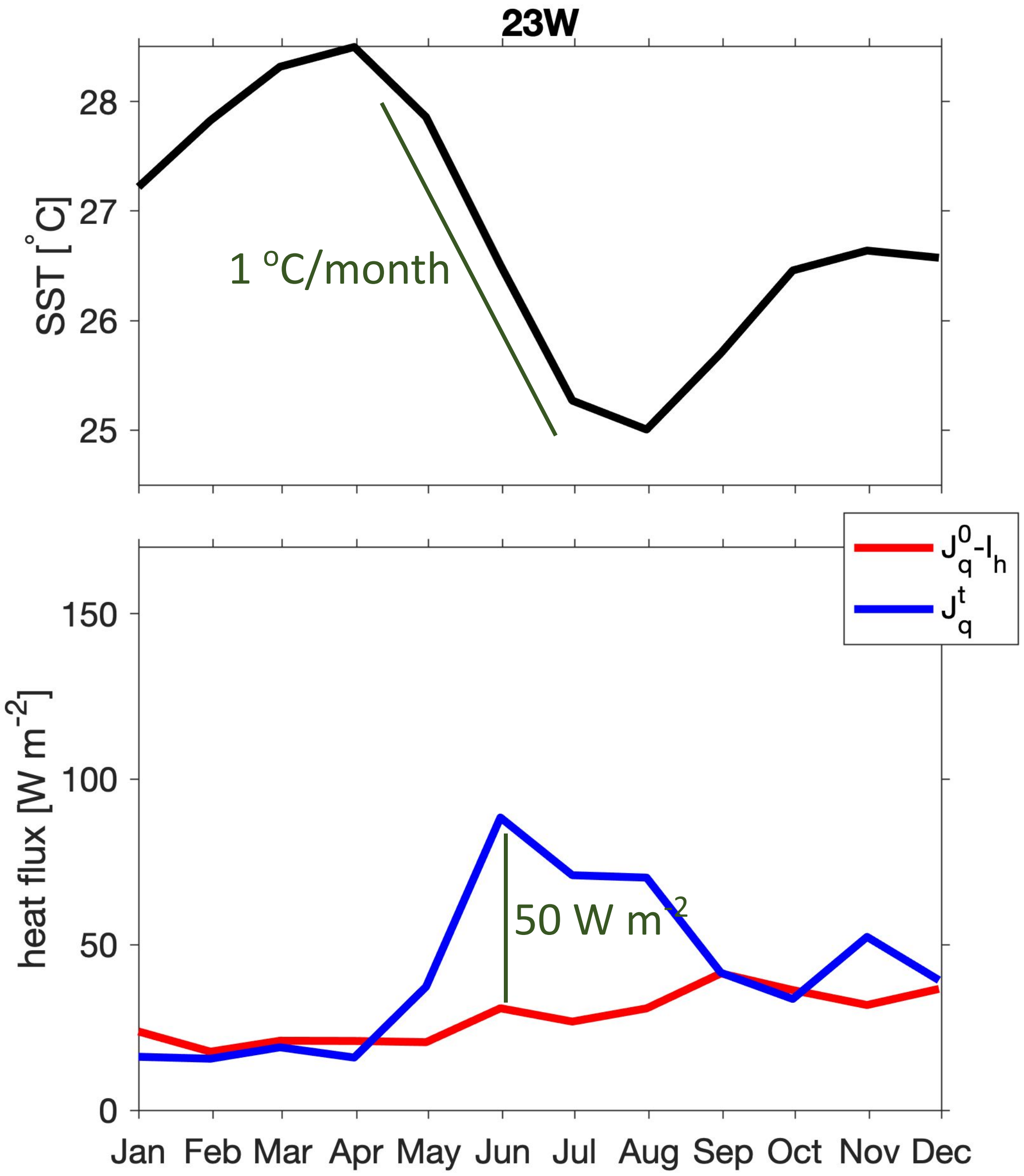


$$\frac{\partial T}{\partial t} = \frac{1}{\rho C_p}\frac{\partial J_q^t}{\partial z}$$

$$\approx \frac{1}{4\times 10^6}\,\frac{50}{21}$$

→ 1.5 °C/month

0, 110W
no hourly flux values

Summary

- deep diurnal mixing cycle present at 10W, 23W – similar to deep cycle at 140W
- wind-dependent phasing with depth
- near-surface magnitudes are similar at all 3 sites
- depth dependencies unclear in ACT because mixing is confined to thinner, shallow layers
- turbulent heat transport through ML at 23W > required for seasonal SST changes
- ADCP marginally measures MI layer at 10W, 23W

Proposed New Deployments

shallower sensors
reduced vertical spacing
(nominal 10 m separations)

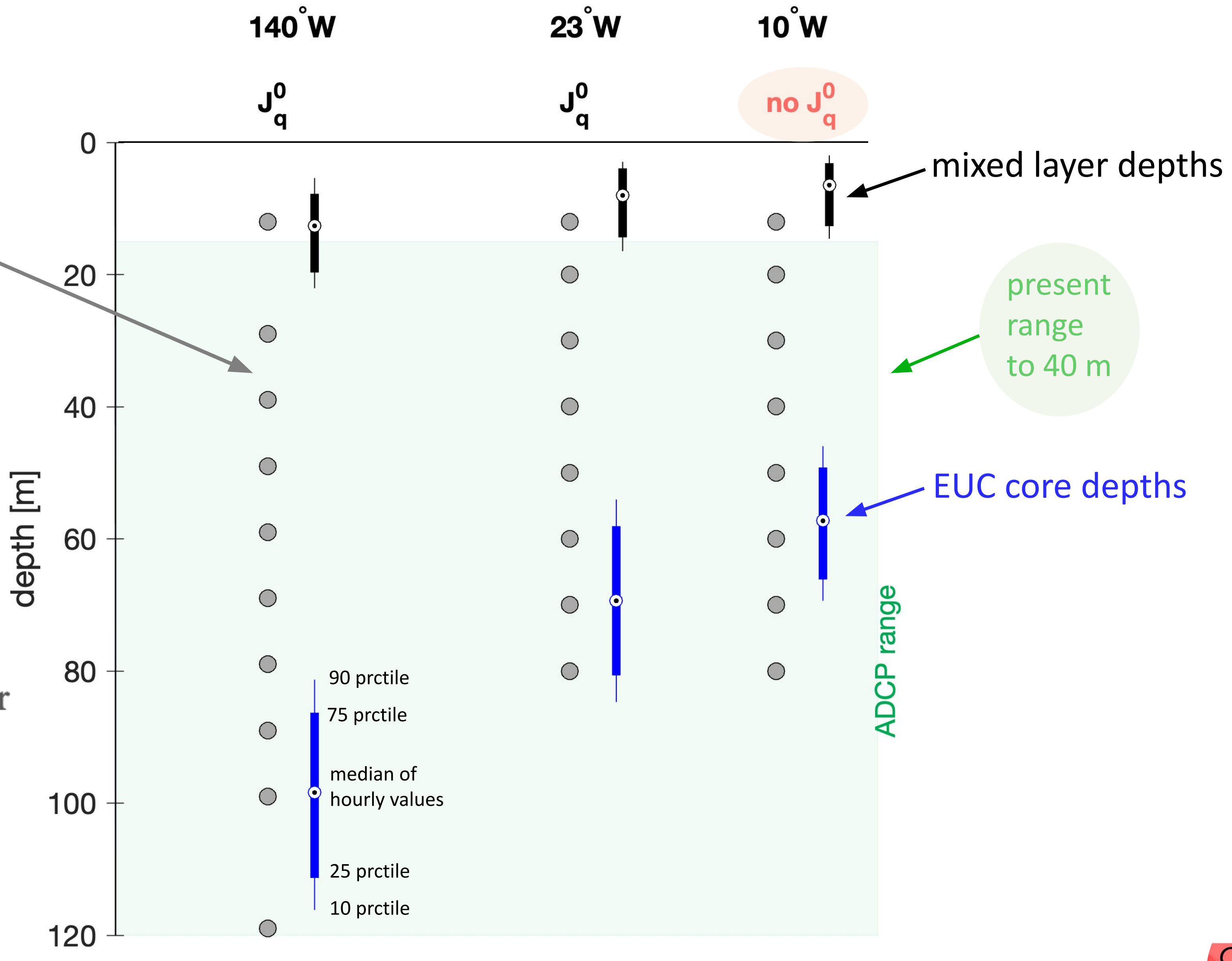
- more shallow sensors
- better resolution of $\frac{\partial J_q^t}{\partial z}$

<u>Also, *some issues* to consider ?</u>

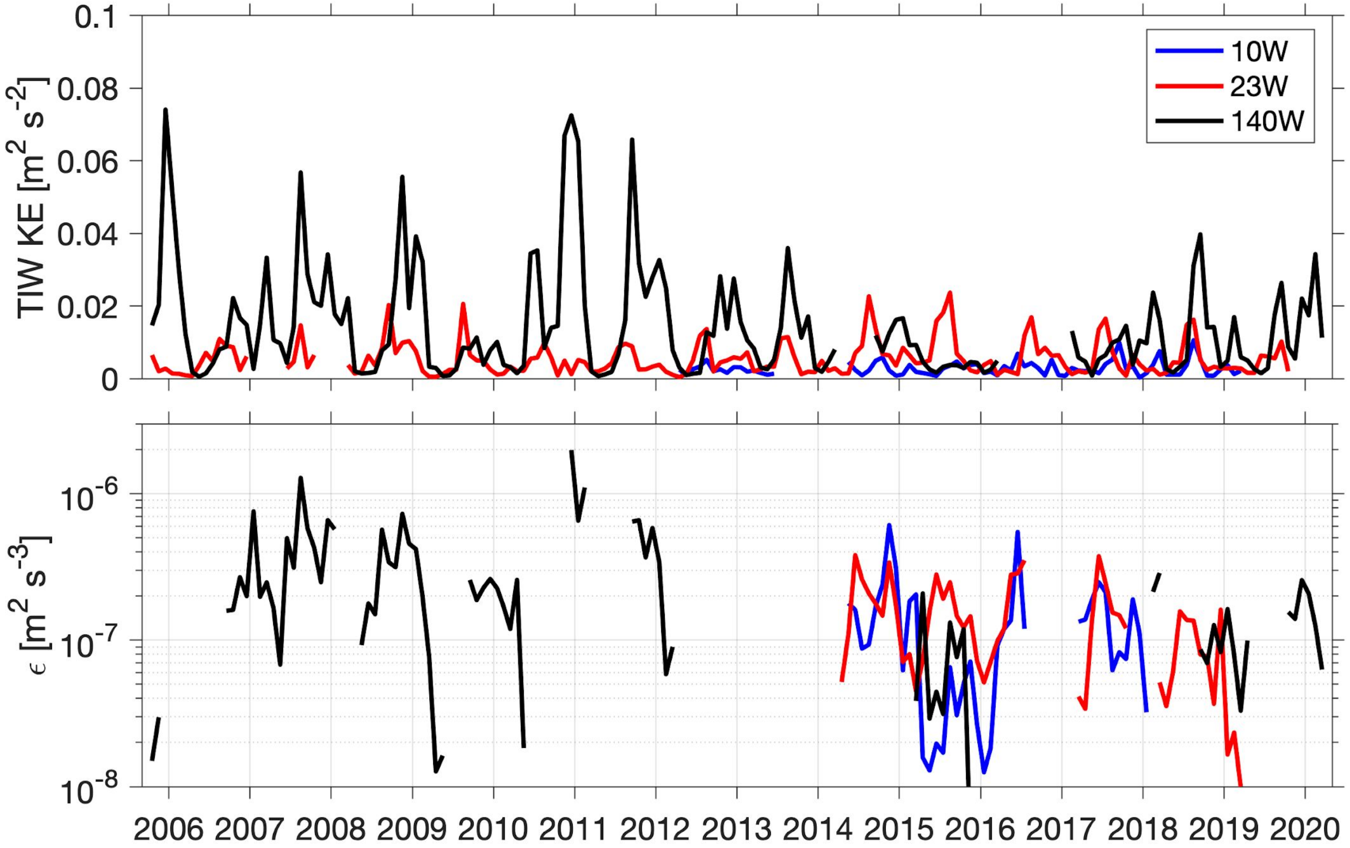
are there ways to get better near-surface velocities?

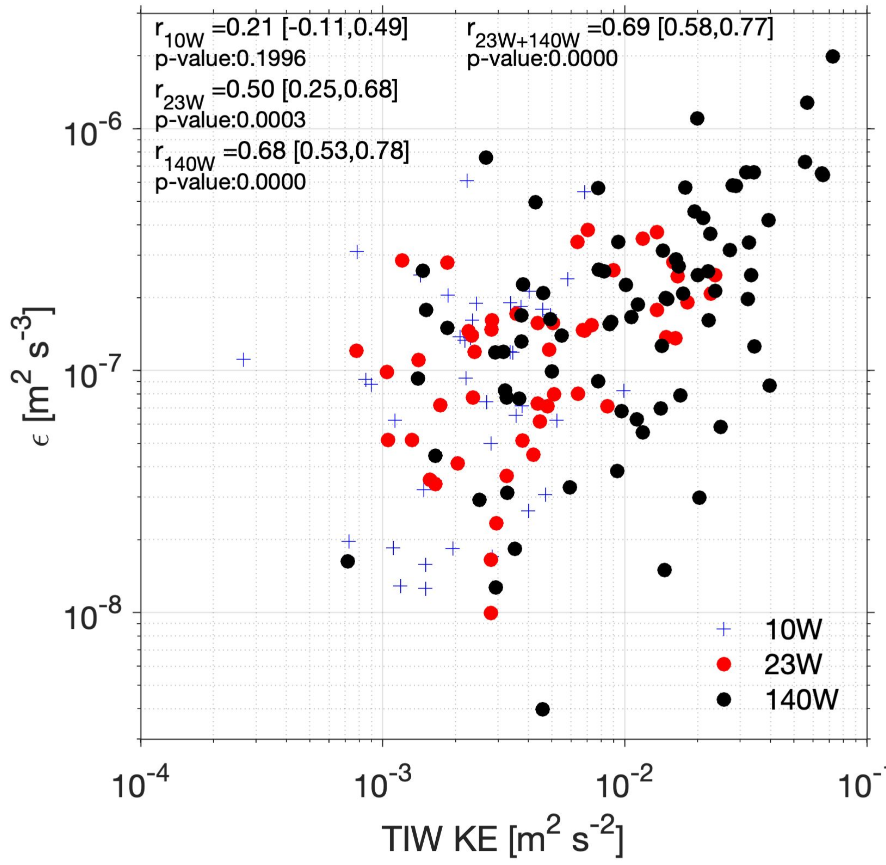
- side lobe suppression / bigger xdr
- reduce beam angle (20º)
- move ADCPs shallower in east

can 0, 10W be made a flux site?

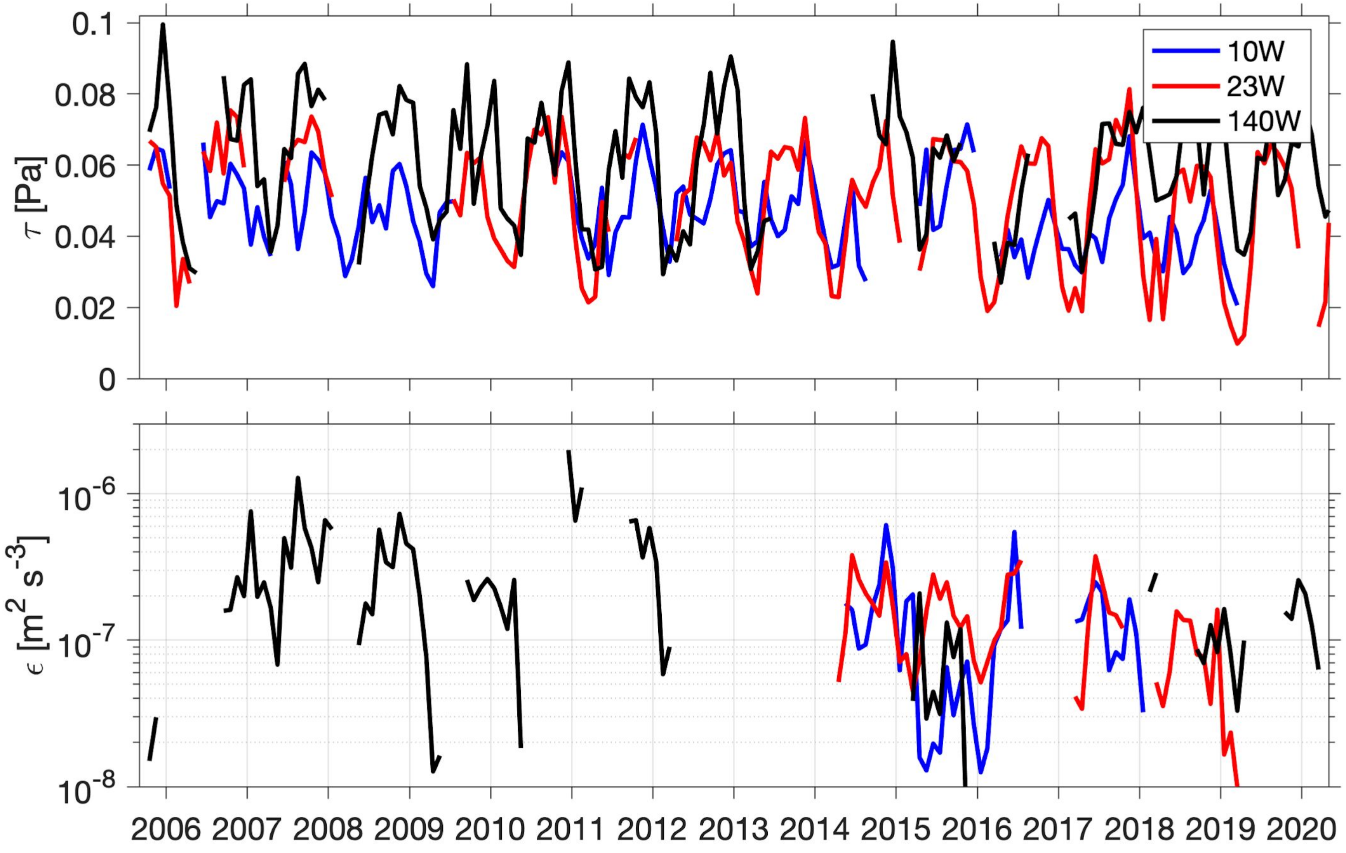


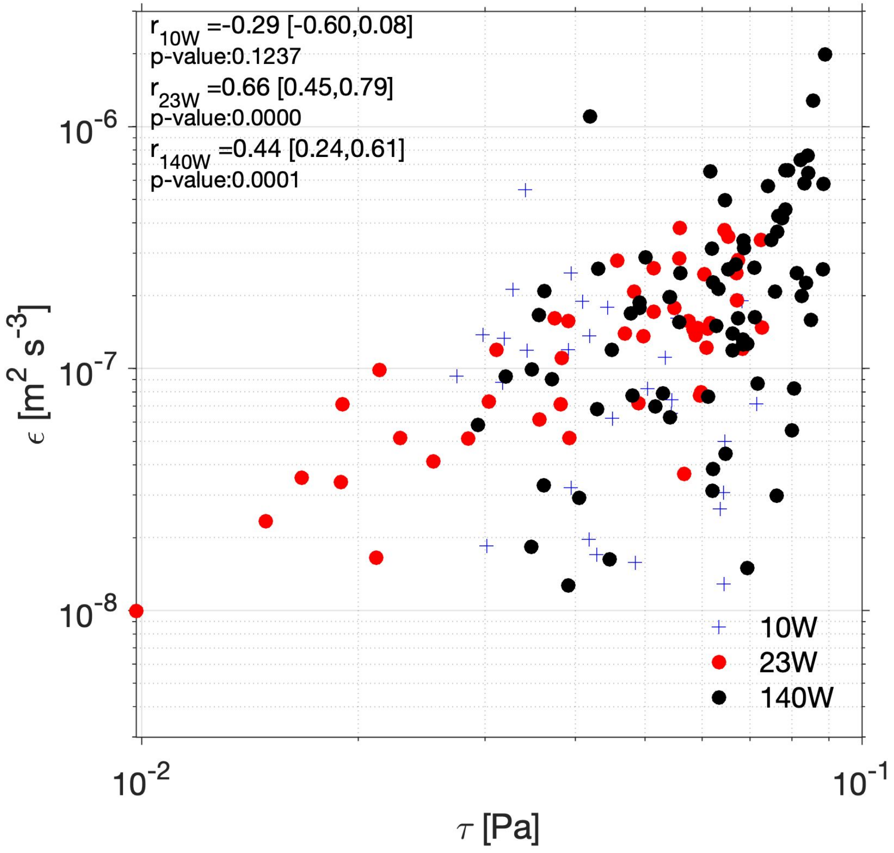
TIW KE and Mixing (ε)





Wind stress (τ) and Mixing (ε)

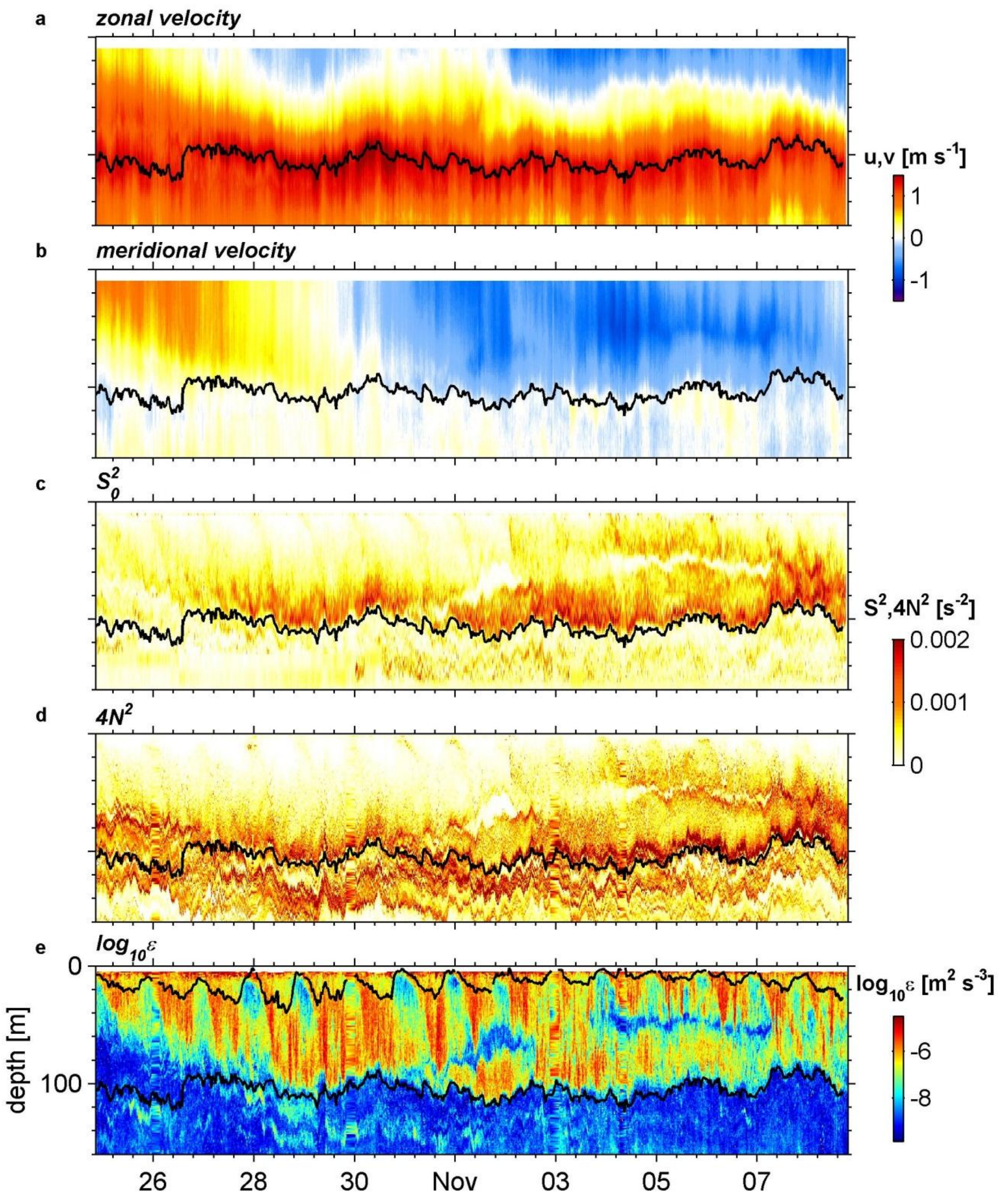




Patterns of Mixing 2008
0, 140W

an example of profiling time series from ship – 16 days

mixing during passage of a tropical instability wave



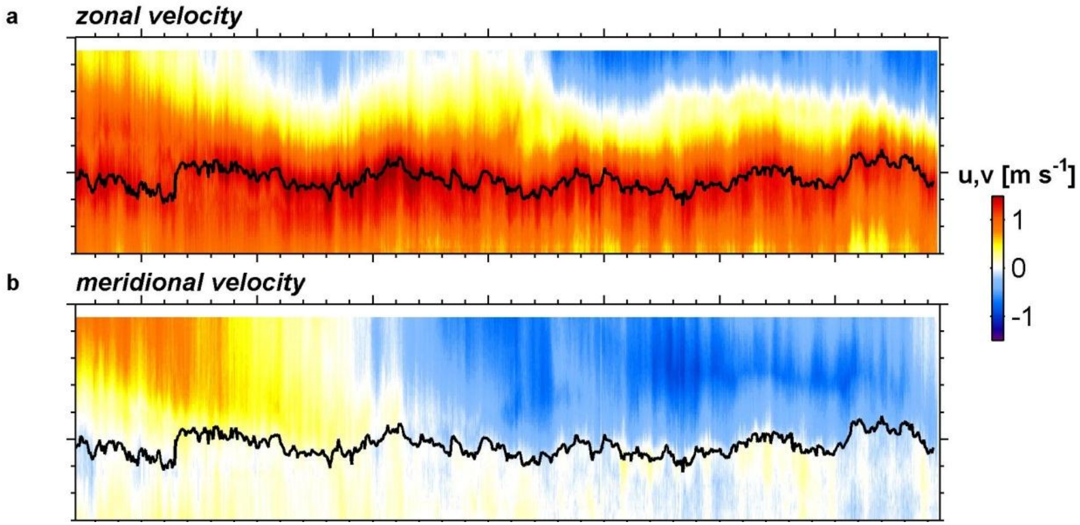
Moum etal, 2009
(Nature Geosci.)

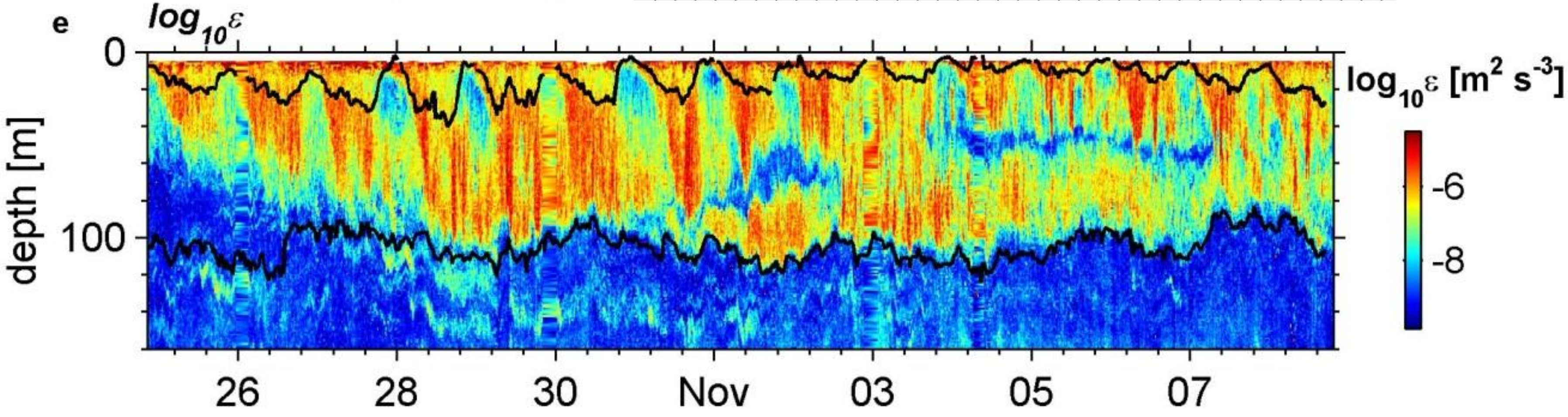
Patterns of Mixing 2008

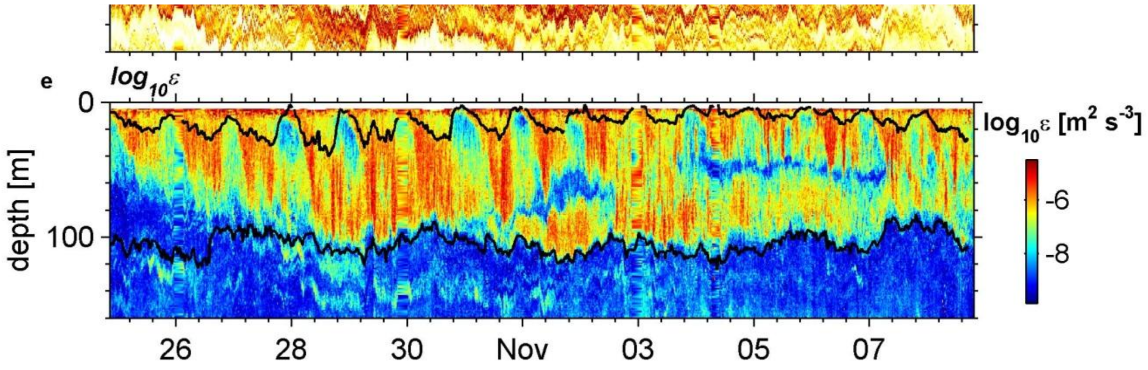
0, 140W

unique from 1984, 1987, 1991, 2014

a new lesson each time !







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