Impacts of rainfall on near-surface turbulence

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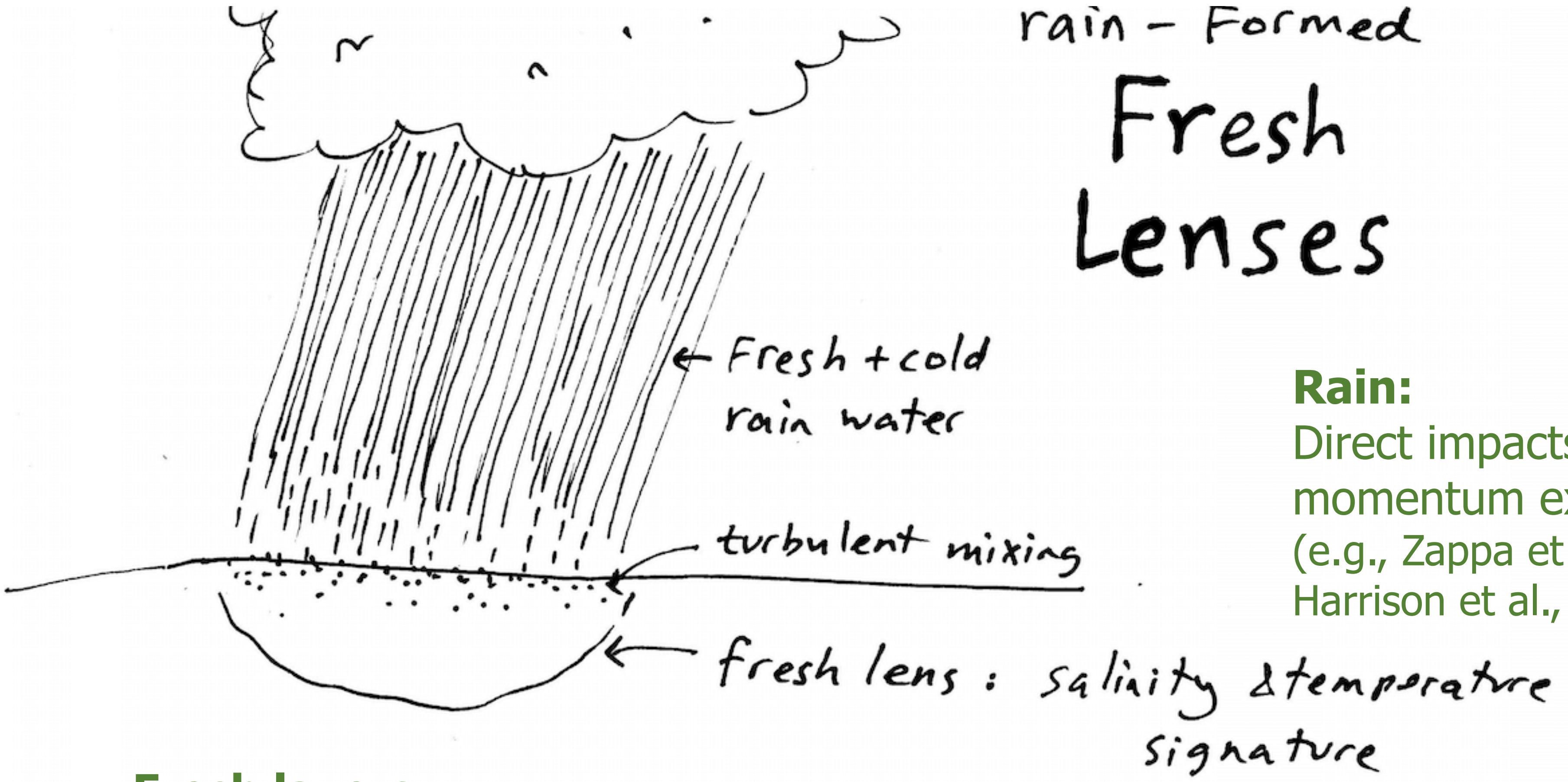


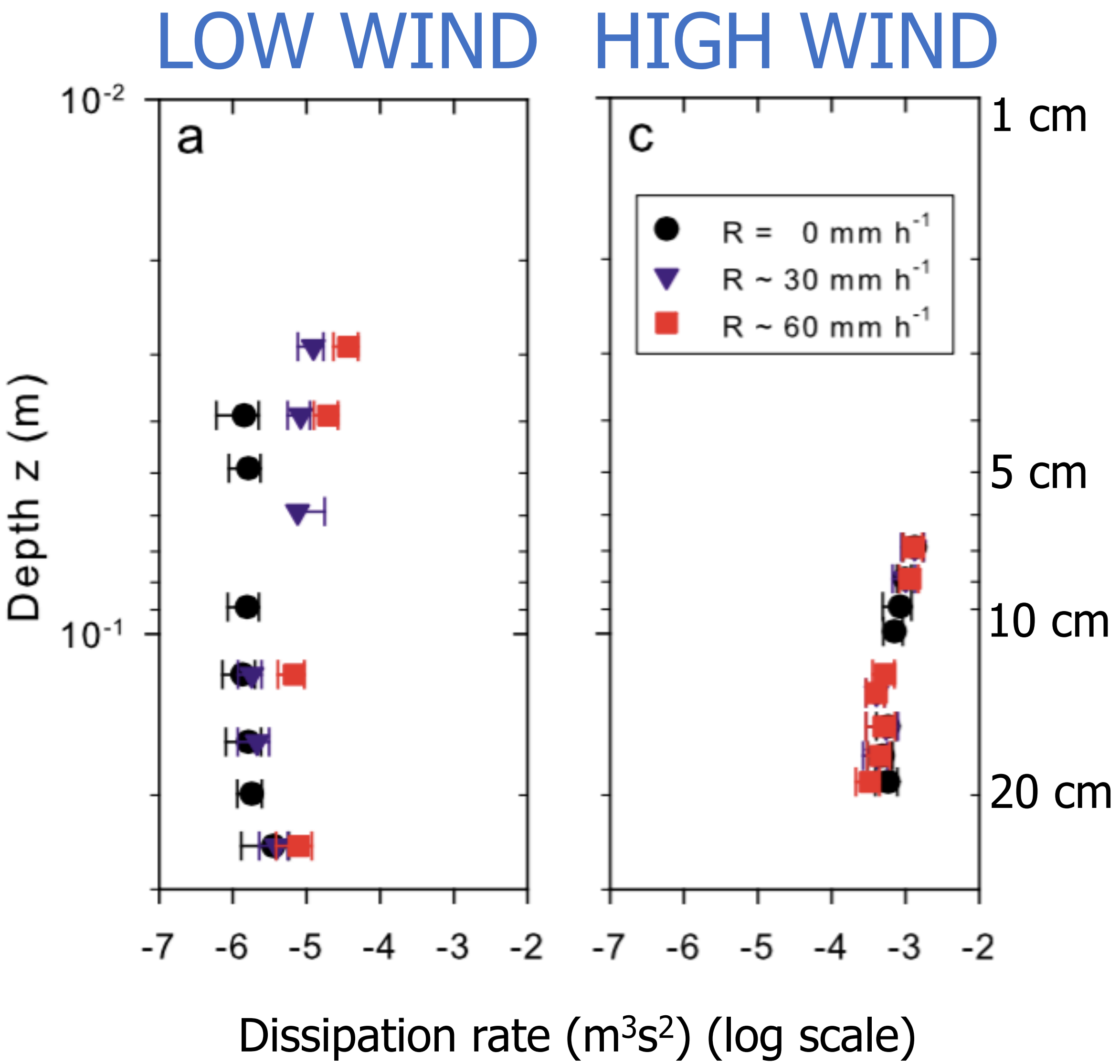
Rain:
Direct impacts on gas and momentum exchange
(e.g., Zappa et al., 2009; Harrison et al., 2012)

Fresh layers:
Suppress mixing below the lens
→ affect air-sea interaction
(e.g., Wijesekera et al., 1999)

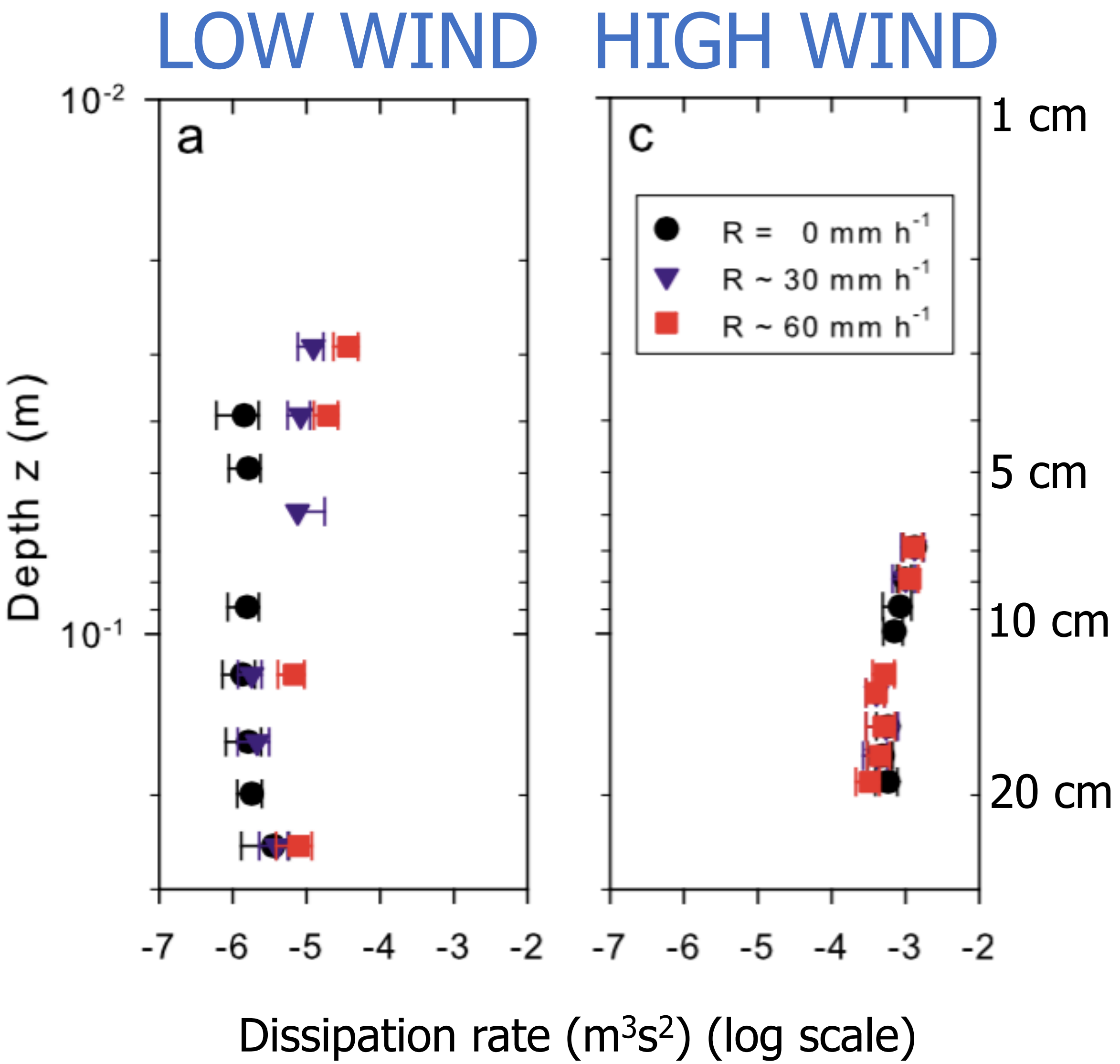
Lab experiments (Harrison et al., 2012):

Low winds → rain enhances TKE dissipation rate

High winds → wind dominates



Rain impact on turbulence can be explained by considering the Kinetic Energy Flux (KEF) of rain vs wind



$$KEF_r = \frac{1}{2}\rho_d w^2 R,$$

$$KEF_w = \rho_a u_*^3$$

R = rain rate,
ρ_d = raindrop density,
ρ_a = air density,
w = vertical raindrop velocity
u^* = friction velocity

Rain-driven turbulence matters when $KEF_{rain} > KEF_{wind}$

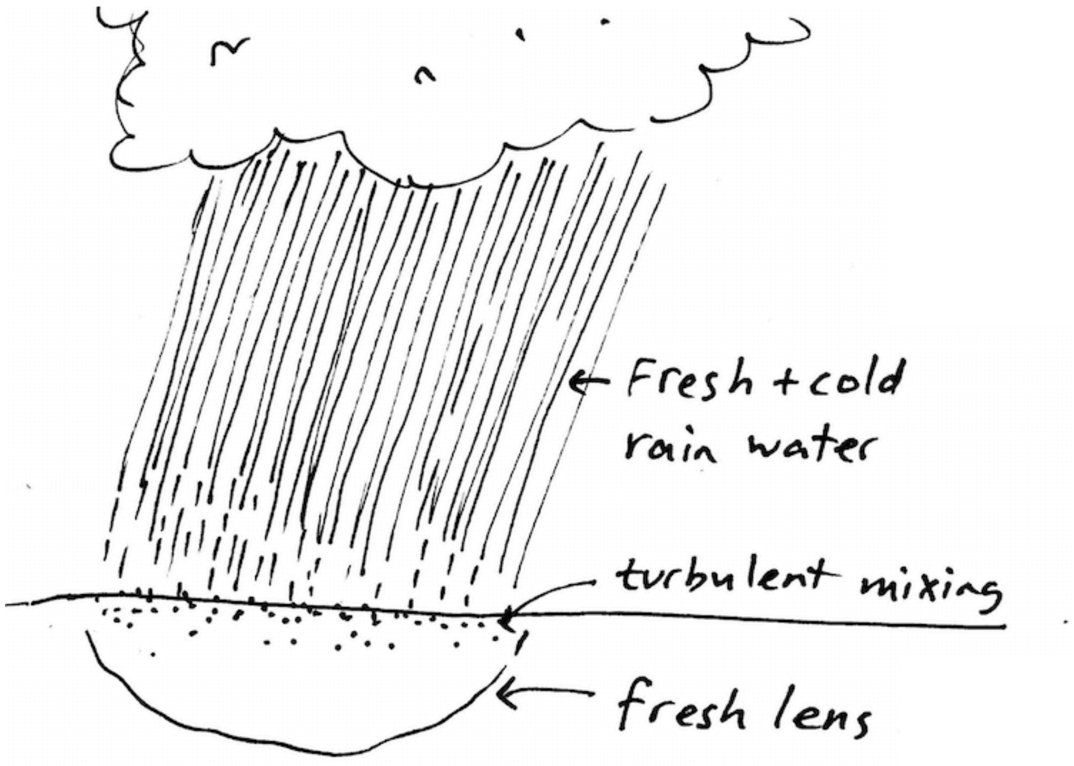
Both wind and rain drive the ocean's response to rainfall, but the physics are not well understood

When are rain effects important relative to wind?

How deep do raindrops mix?

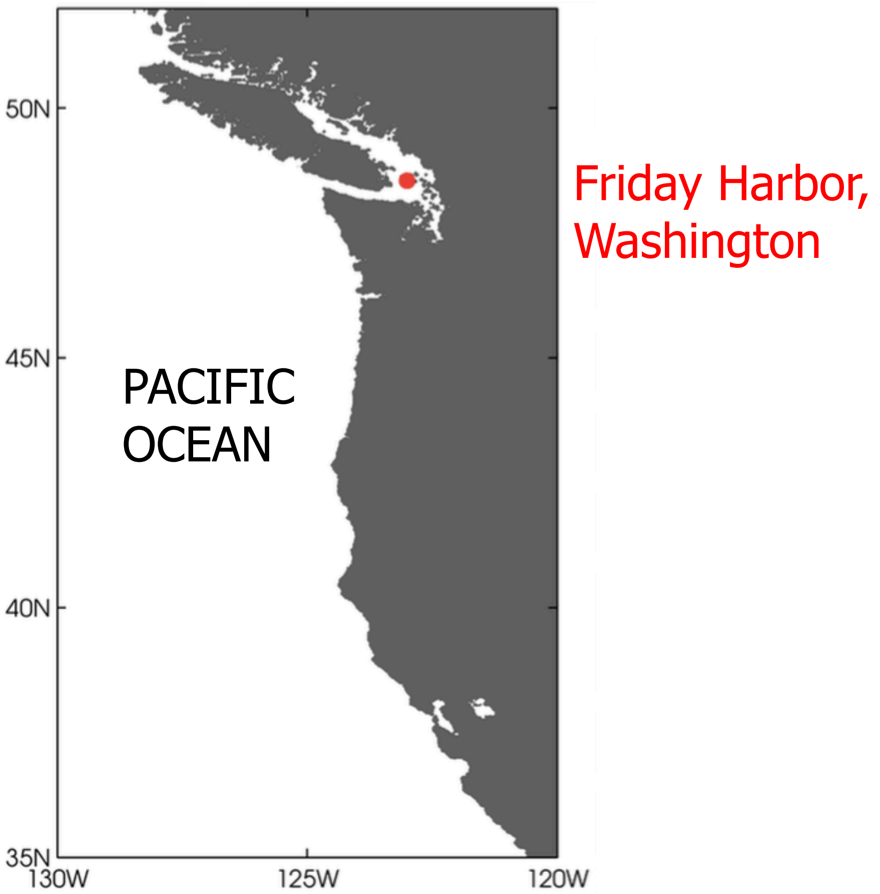
How does dissipation rate decay with depth?

How does raindrop size affect mixing?



Friday Harbor Rain Experiment

Dec 2015-Mar 2016



Meteorological sensors:
Rain rate, wind speed/direction, air temperature, pressure, humidity

Disdrometer:
Raindrop size distribution

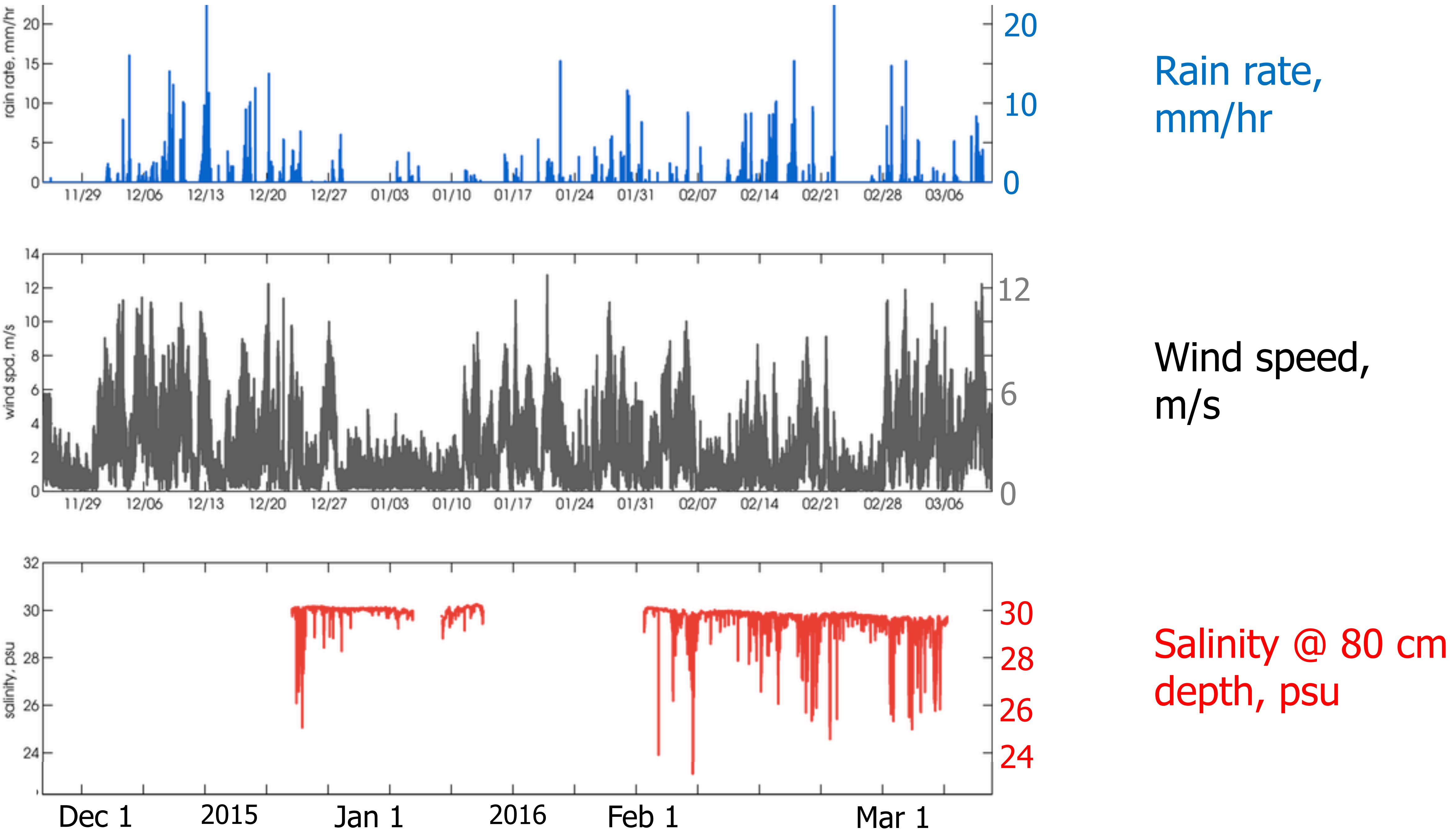
In-water instruments:

Aquadopp: pulse-coherent Doppler velocity profiler → TKE dissipation rate from 20 – 70 cm depth (Thomson 2012)

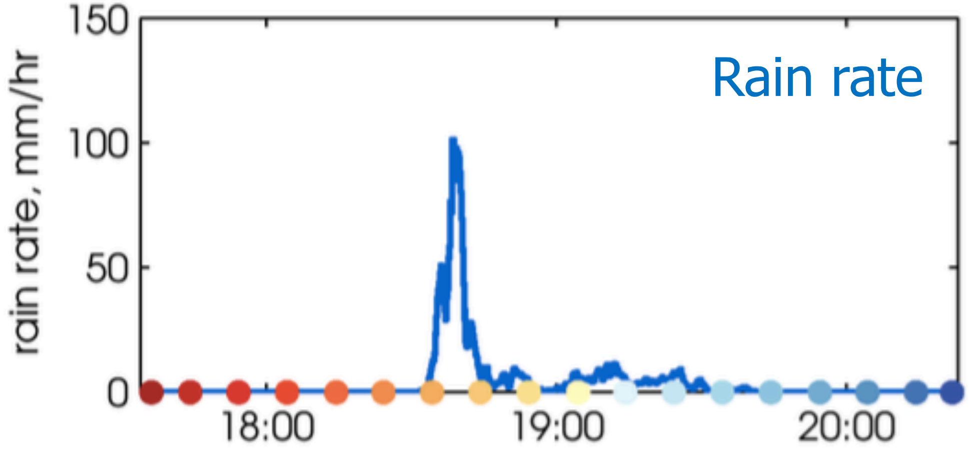
Vectrino: acoustic Doppler velocimeter → TKE dissipation rate from ~3–5 cm

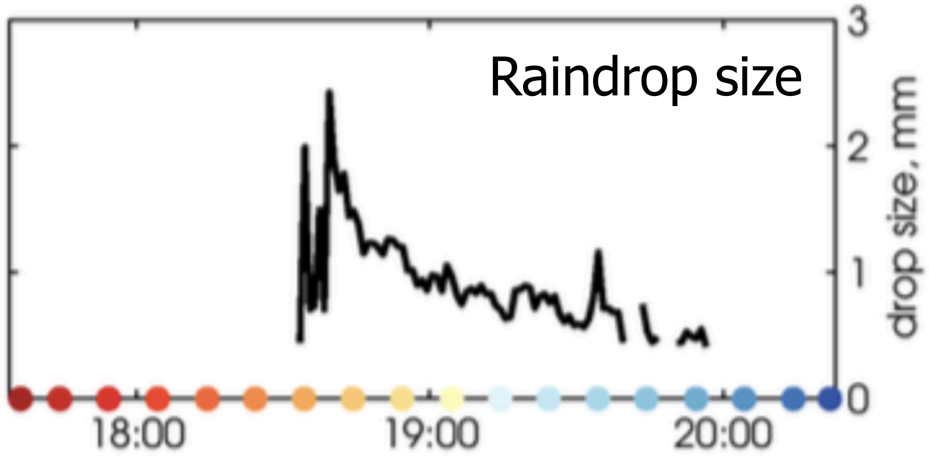
CTD at 80cm

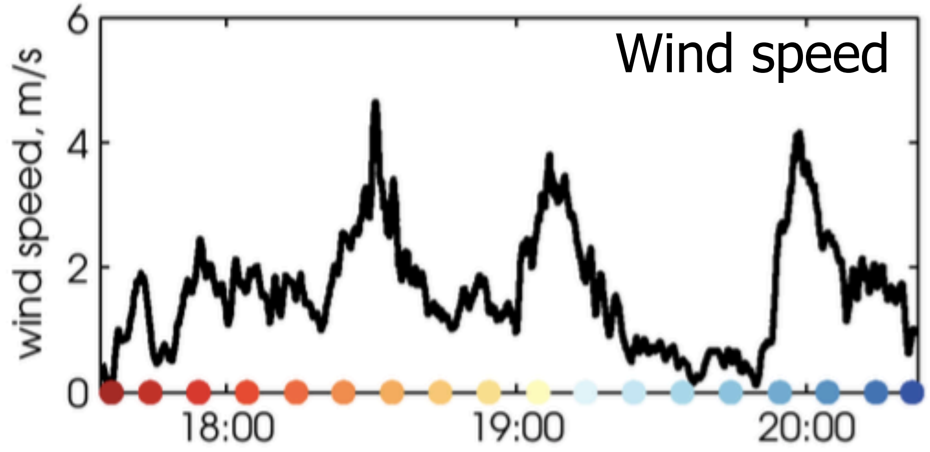
Friday Harbor Rain Expt: a wide range of wind/rain conditions

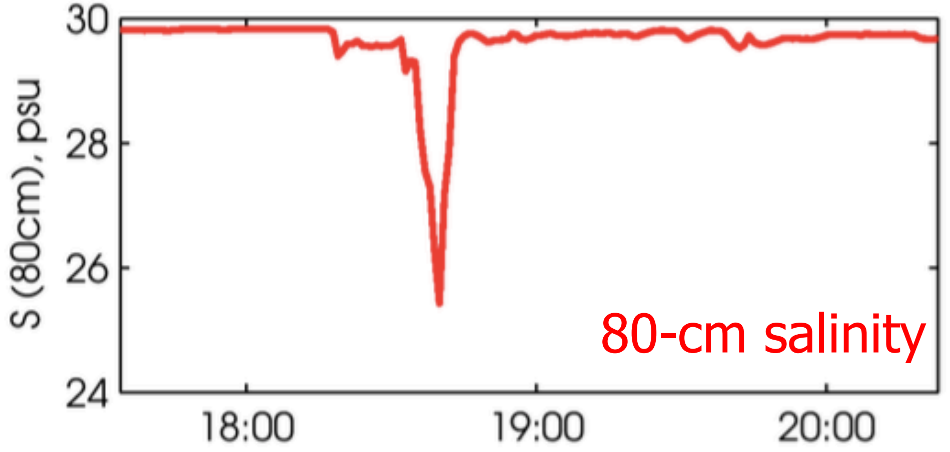


Feb 2016 rain event









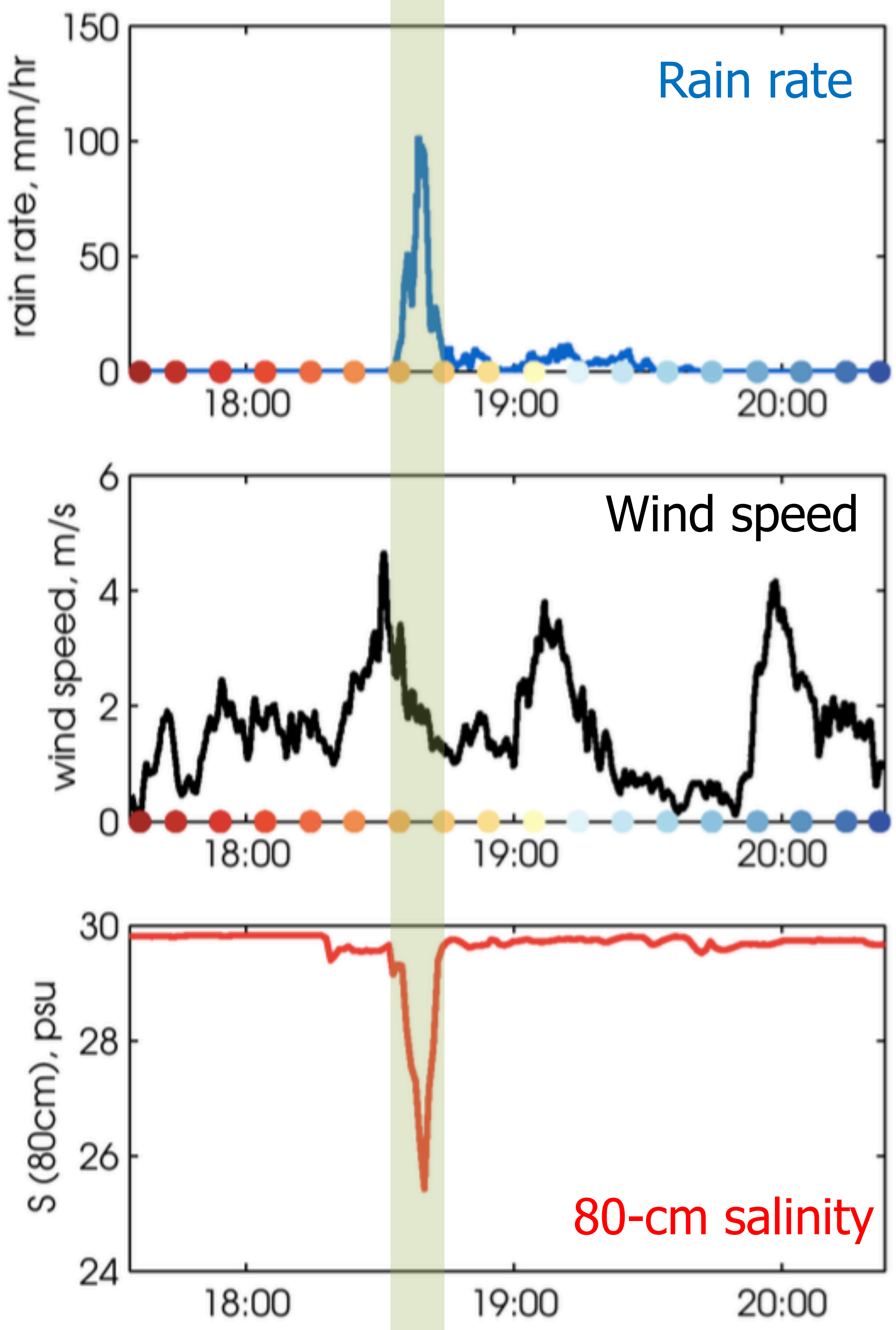
Strong, brief rain with large (2mm) drops.

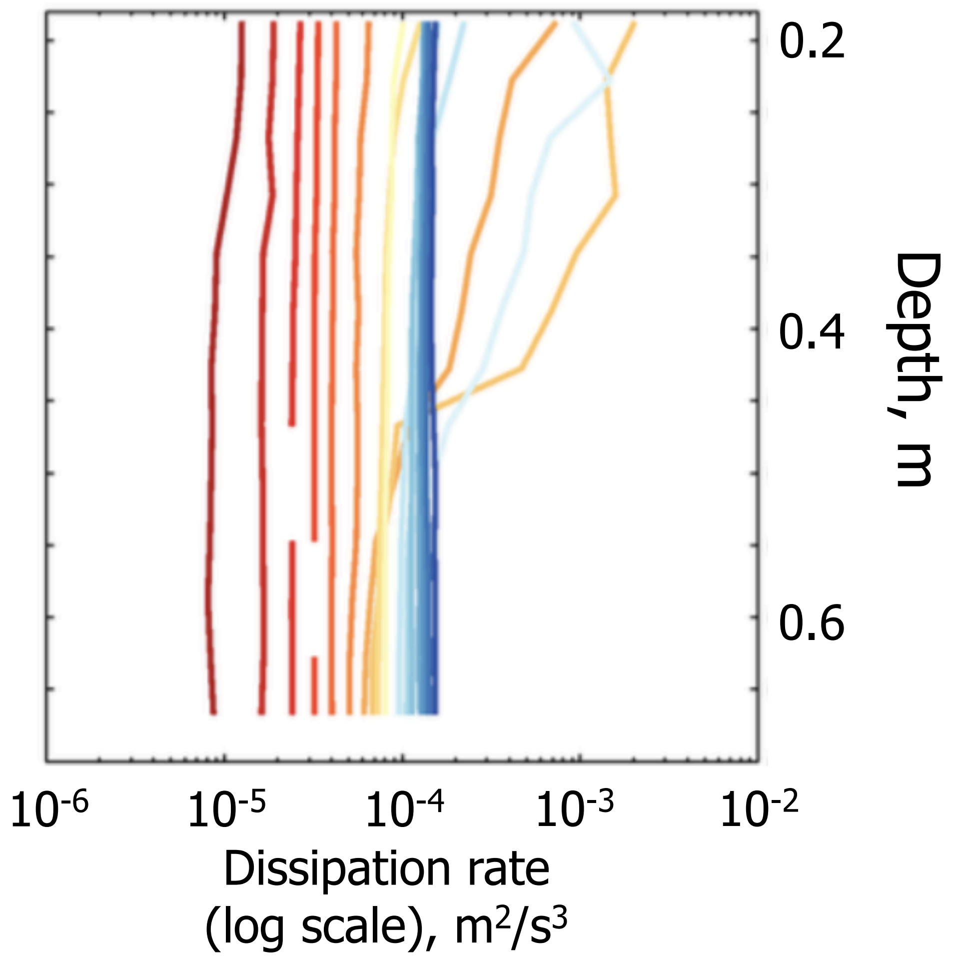
Weak wind (2 m/s) with some gusts

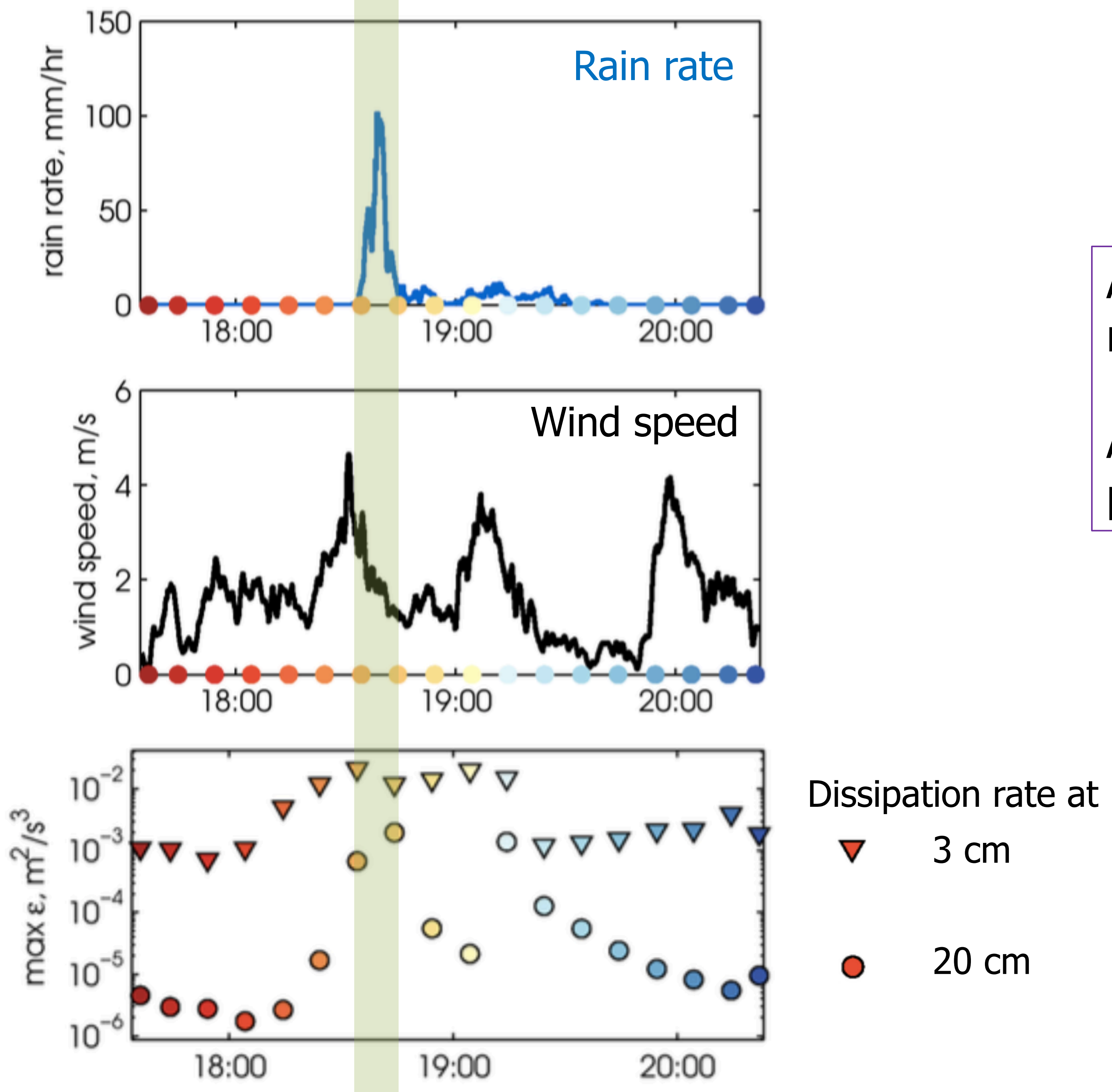
Strong (4 psu), brief salinity anomaly.

Freshwater mixed quickly to 80 cm and then mixed/advected away.

Turbulence down to 50 cm is enhanced by a factor of >10 during rain



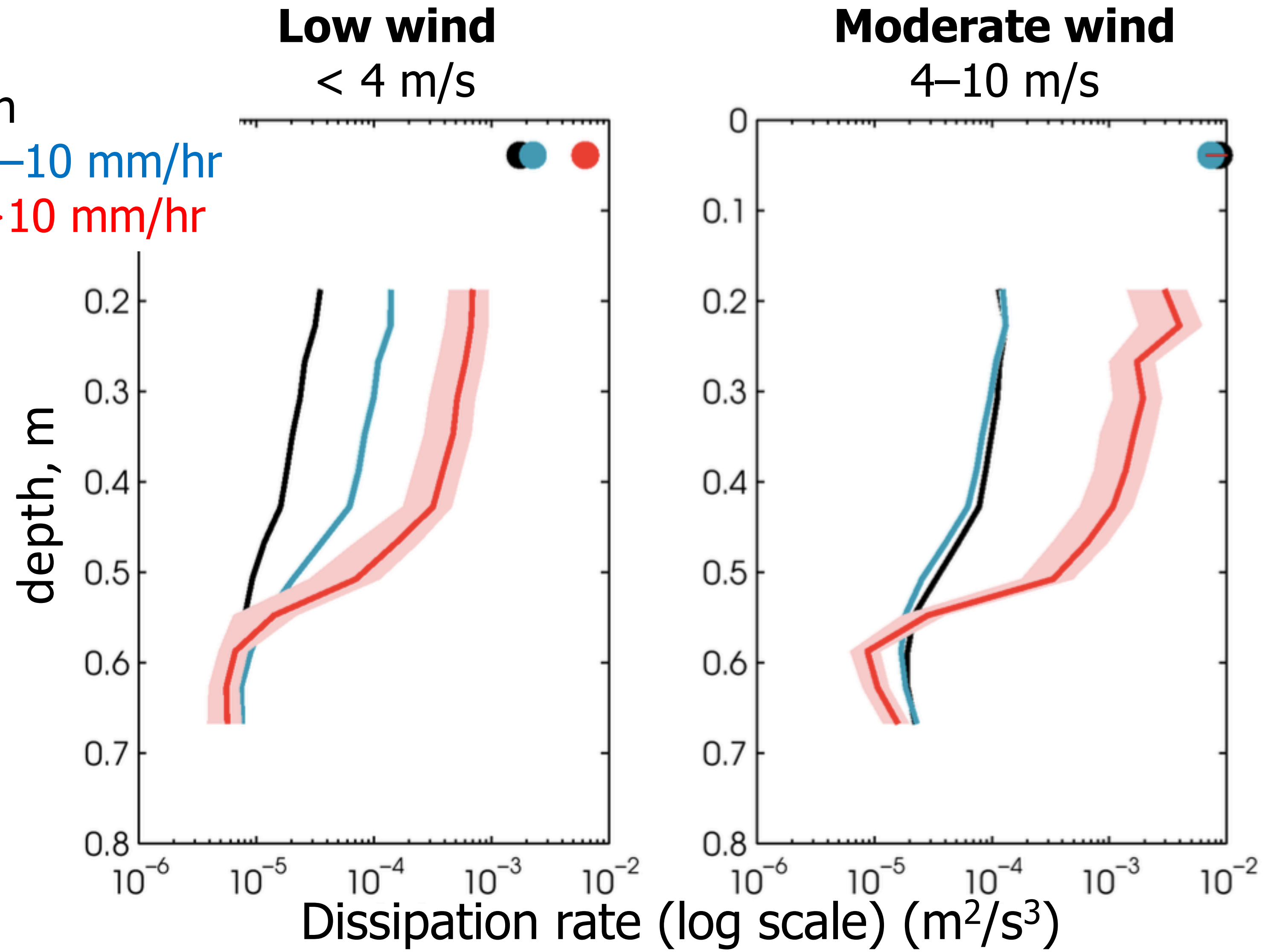




At 3 cm and 20 cm, dissipation rate rises with wind and peaks with rain.

After rain, turbulence at the surface persists but at 20 cm falls off quickly.

Binned dissipation profiles
Rain has a stronger impact in low winds

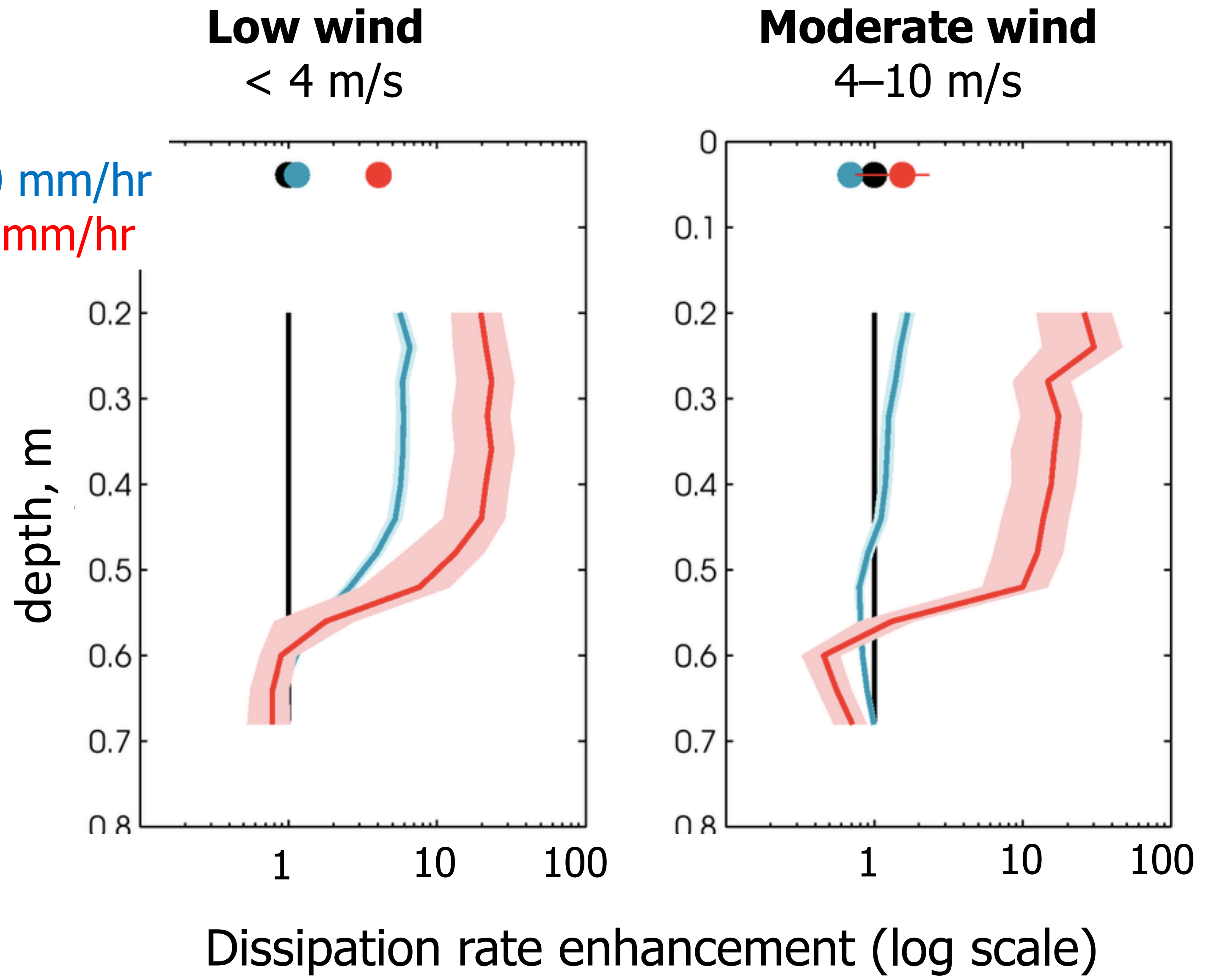


Rain mixes consistently down to ~50 cm

Low wind: even weak rain enhances turbulence

Moderate wind:
only the strongest rain generates appreciable turbulence

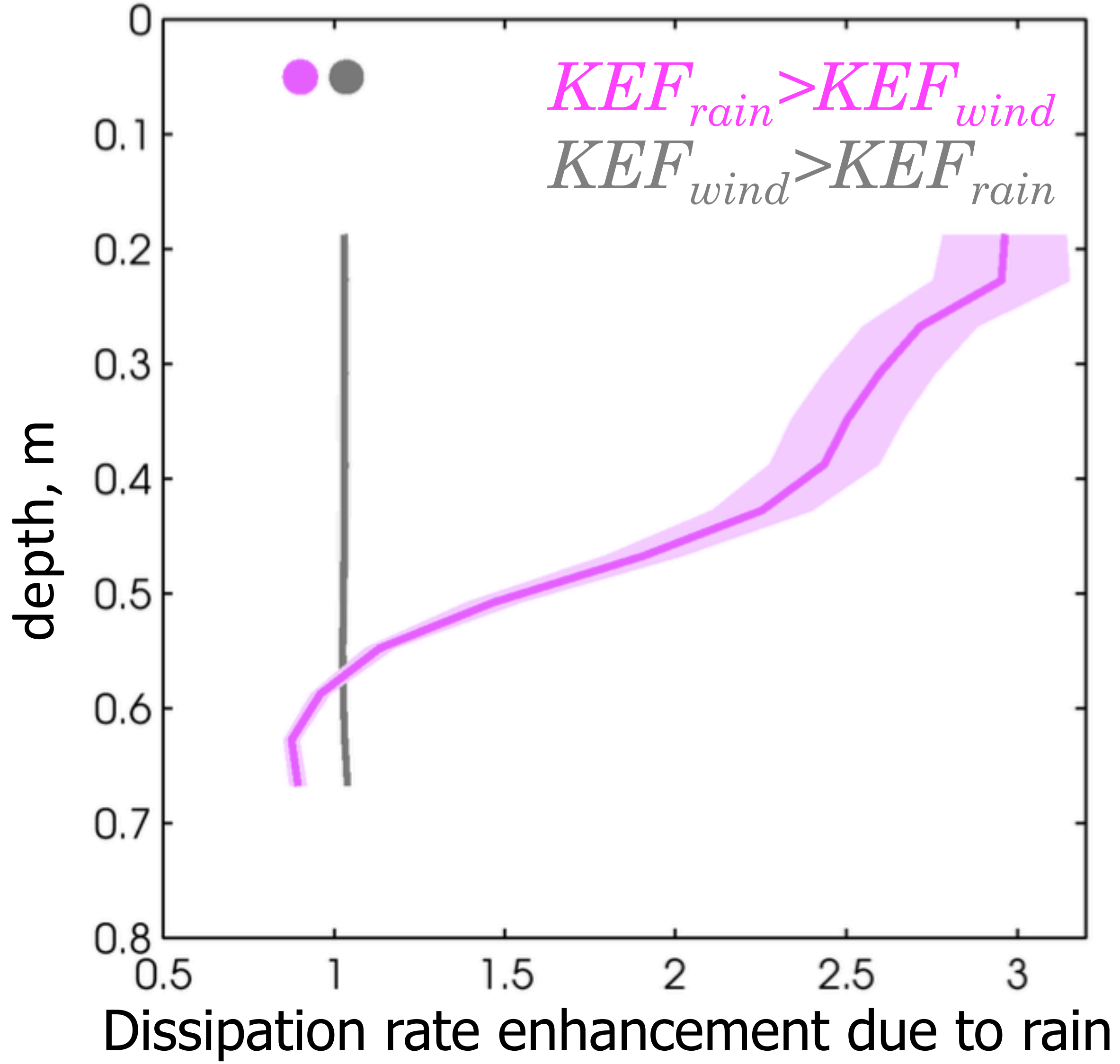
Turbulence enhancement due to rain: $\frac{\varepsilon_{rain}}{\varepsilon_{no\text{-}rain}}$



All winds: strong rain enhances TKE dissipation by a factor of 10-100

Rain enhancement is weaker at the surface than below 20 cm.

Kinetic Energy Flux (KEF) explains the relative importance of rain and wind (consistent with Harrison et al., 2012)

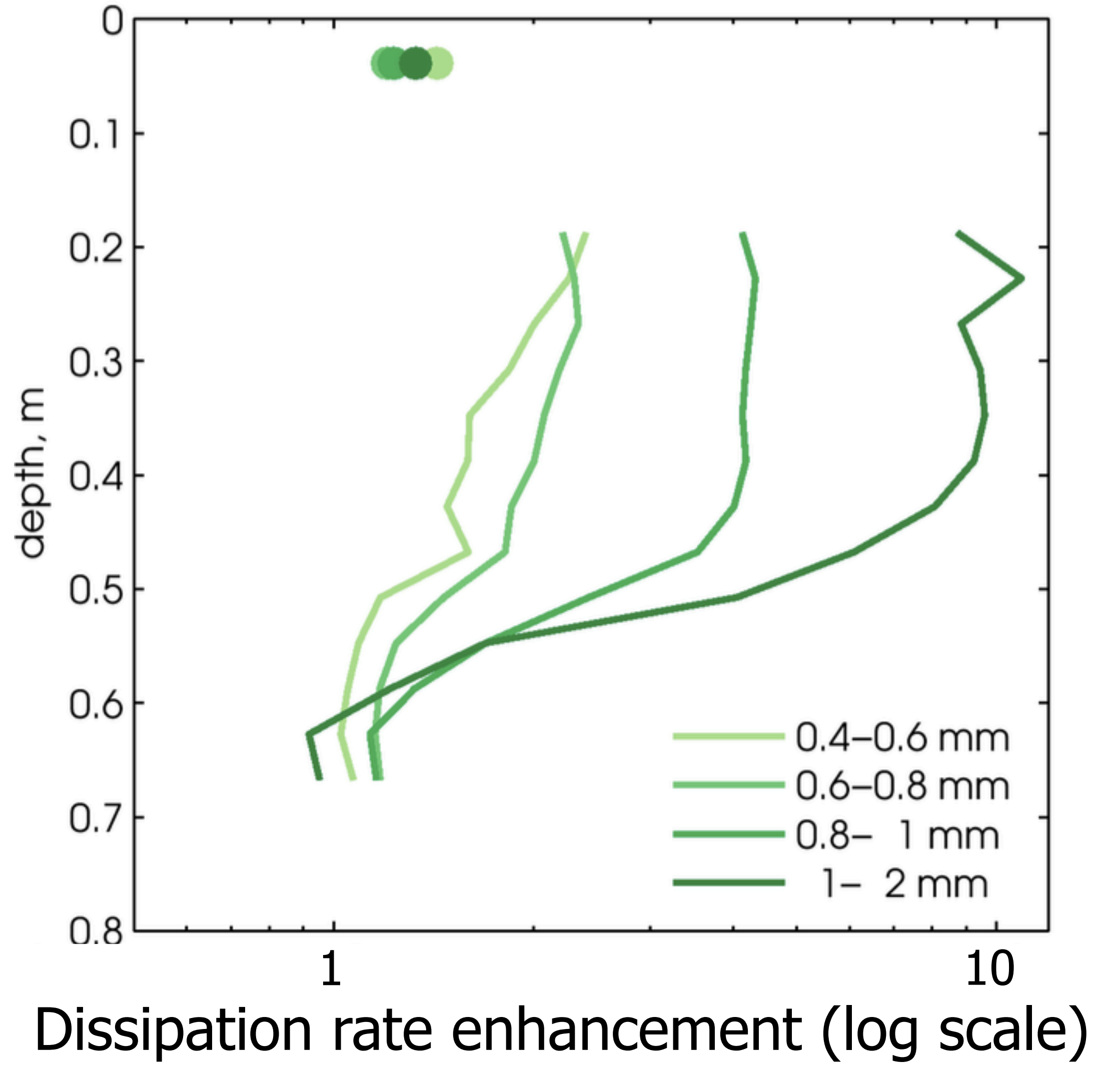


Below 20 cm, rain generates enhanced turbulence when $KEF_{rain} > KEF_{wind}$

Near the surface, turbulence is *suppressed* for $KEF_{rain} > KEF_{wind}$

… thin rain layer suppresses mixing?

Dissipation rate is enhanced for bigger raindrops



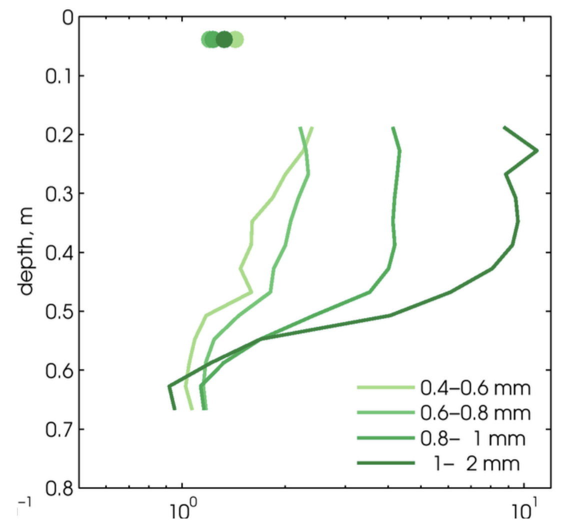
Below 20 cm, bigger raindrops = stronger turbulence.

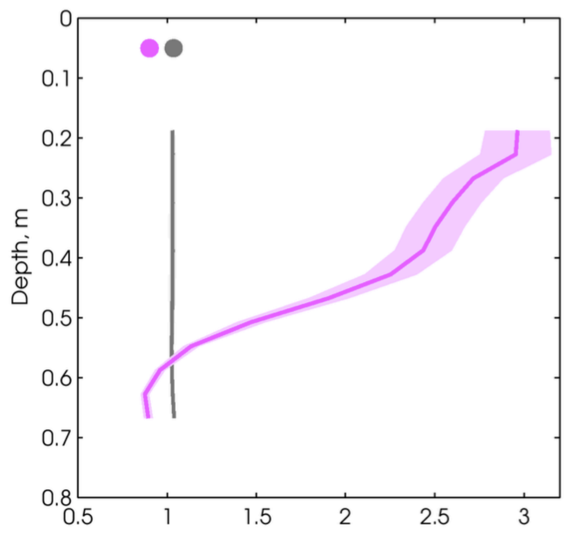
Mixing depth does not appear to depend on drop size.

At the surface, no relationship between dissipation rate and drop size.

Summary

- Rain enhances turbulence when wind is relatively weak.
- Stronger rain drives stronger turbulence below ~20 cm, but at the surface rain suppresses turbulence – thin rain layer suppresses mixing?
- Turbulence generated by rain penetrates to ~50cm, independent of rain rate / drop size – much deeper than suggested by lab experiments (~10cm).





Thank you

Theoretical regime for which rain generates stronger turbulence than wind:

$$KEF_r = \frac{1}{2}\rho_d w^2 R,$$

$$KEF_w = \rho_a u_*^3$$

→ rain effects on the surface can be significant even at high winds