Near-surface stratification effects in the SPURS field campaigns

Carol Anne Clayson, Alec Bogdanoff*, Tom Farrar,
Jim Edson*+, Lou St. Laurent, Ray Schmitt
Woods Hole Oceanographic Institution

** Previously at*
+Currently at U. Connecticut

Research Objectives

- Understand upper ocean mixing processes occurring under stable conditions arising from diurnal warming and freshwater flux variability
- SPURS 1
  - Obtain microstructure turbulence measurements to document mixing processes operating within the salinity maximum region
  - Combine with buoy and other data
- SPURS 2
  - Measure the air-sea fluxes of heat, moisture, and momentum from a ship-based platform
  - Measure atmospheric boundary layer profiles of pressure, temperature, and humidity
  - In combination with other upper ocean measurements investigate the effect of air-sea fluxes in particular in driving upper ocean salinity budget

Research questions

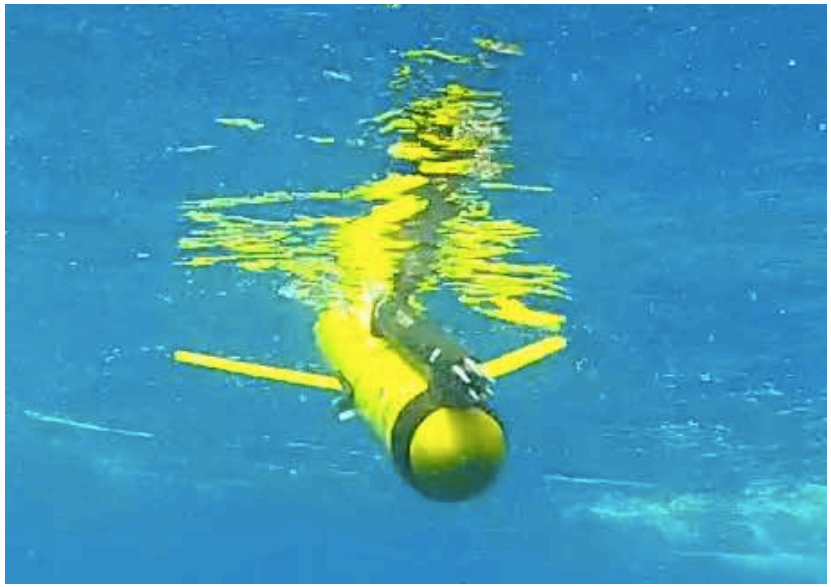
- What is the relationship between the surface forcings of freshwater, momentum, and heat in setting salinity and temperature profiles, and is there a feedback between the salinity and temperature stratification and air-sea fluxes?
- What effect do surface fluxes have in this region on evolution of ocean surface layer?
- How do smaller-scale features of freshwater lenses evolve, and how is this evolution influenced by variations in surface forcing?

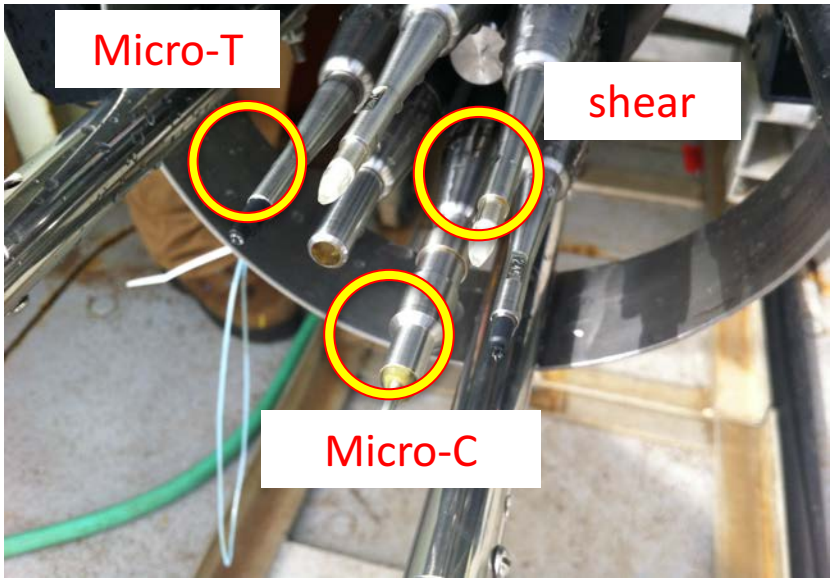
SPURS-1 Turbulence measurements

Shallow Glider (Helo)

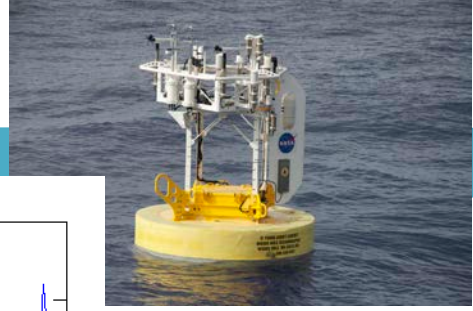
- 60-70m dives
- 1668 profiles
- Within 4 km of WHOI mooring

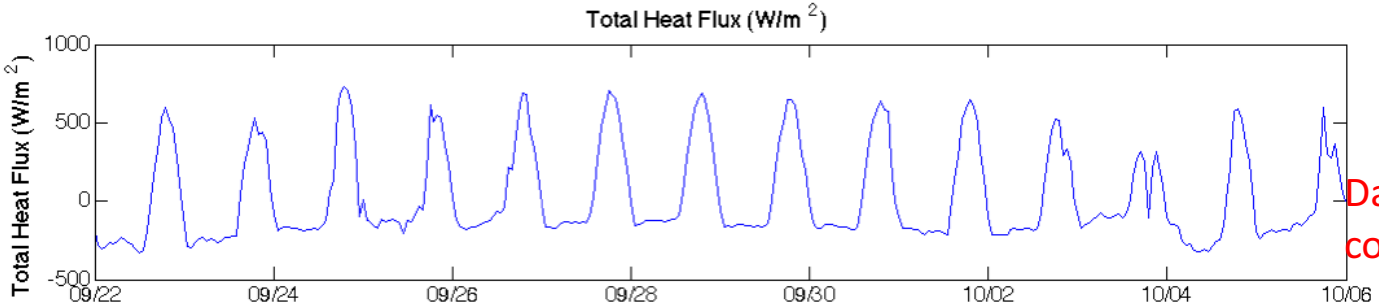
- Dissipation measurements on upwards profiles to near surface



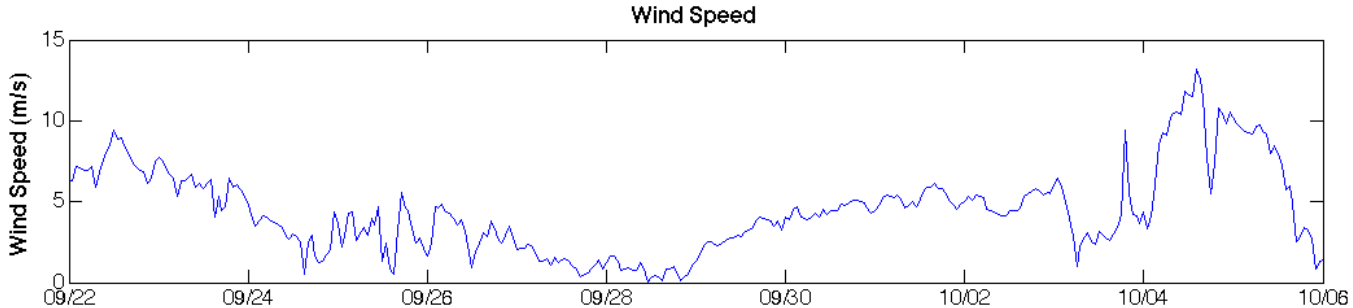


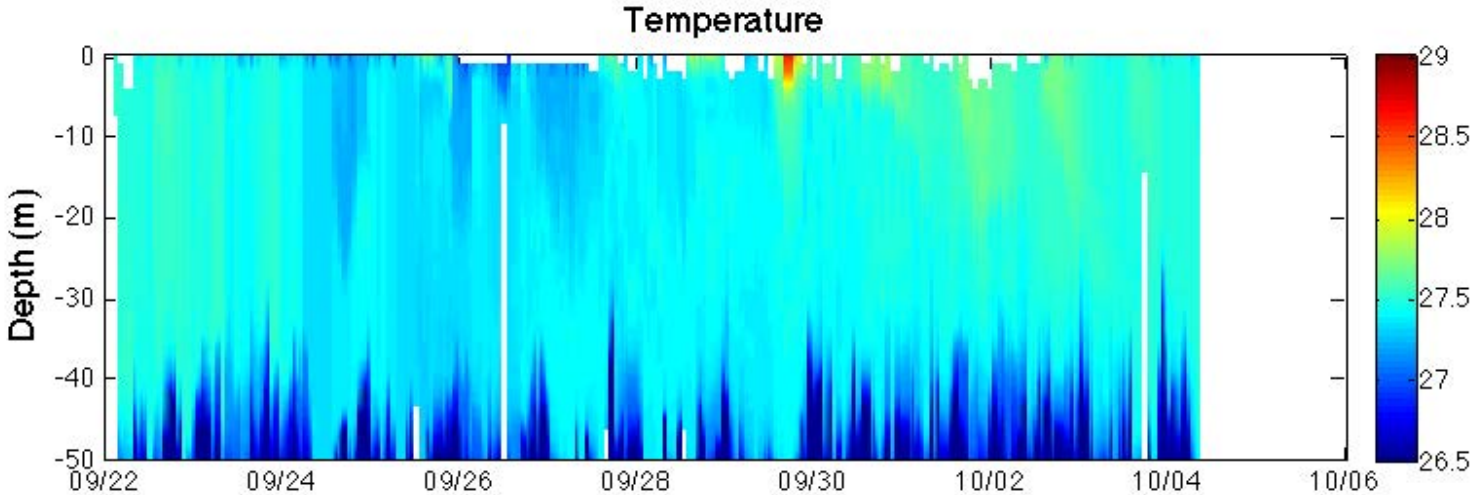
Helo Data Leg 1



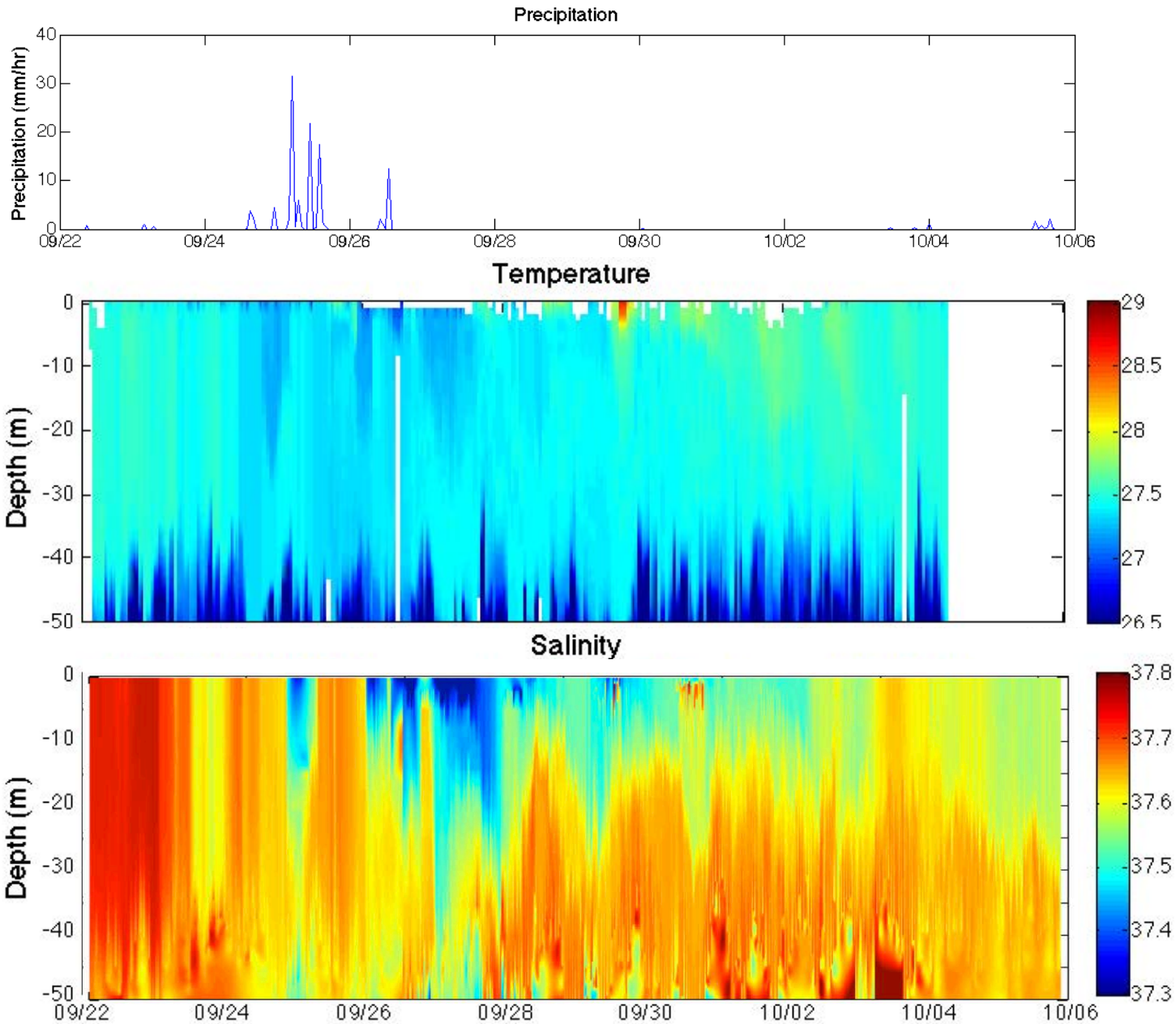


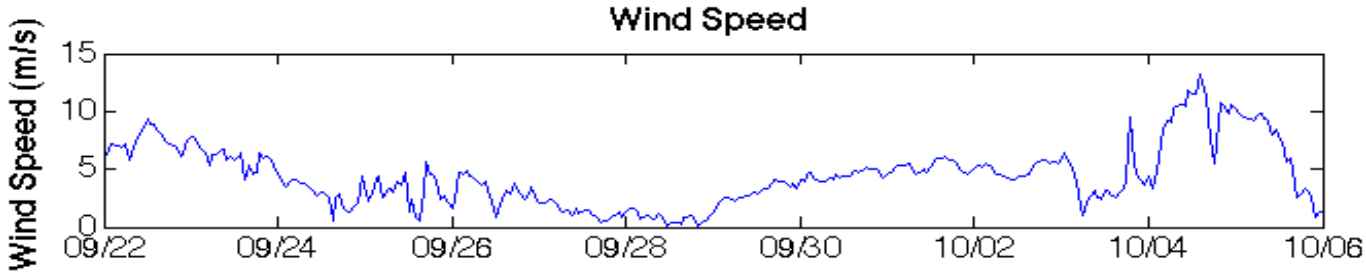
Data from WHOI buoy, courtesy of Tom Farrar



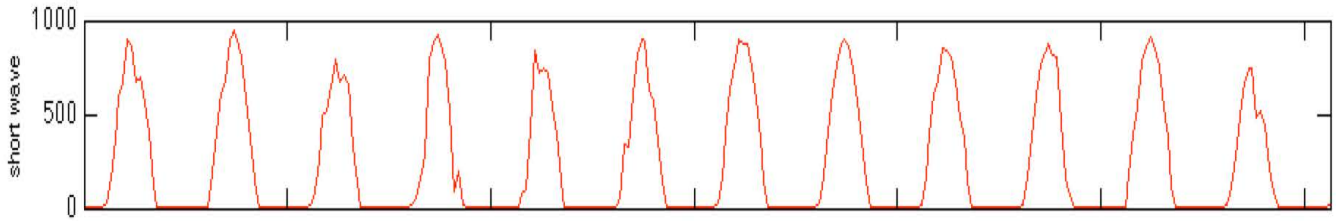


Helo Data Leg 1

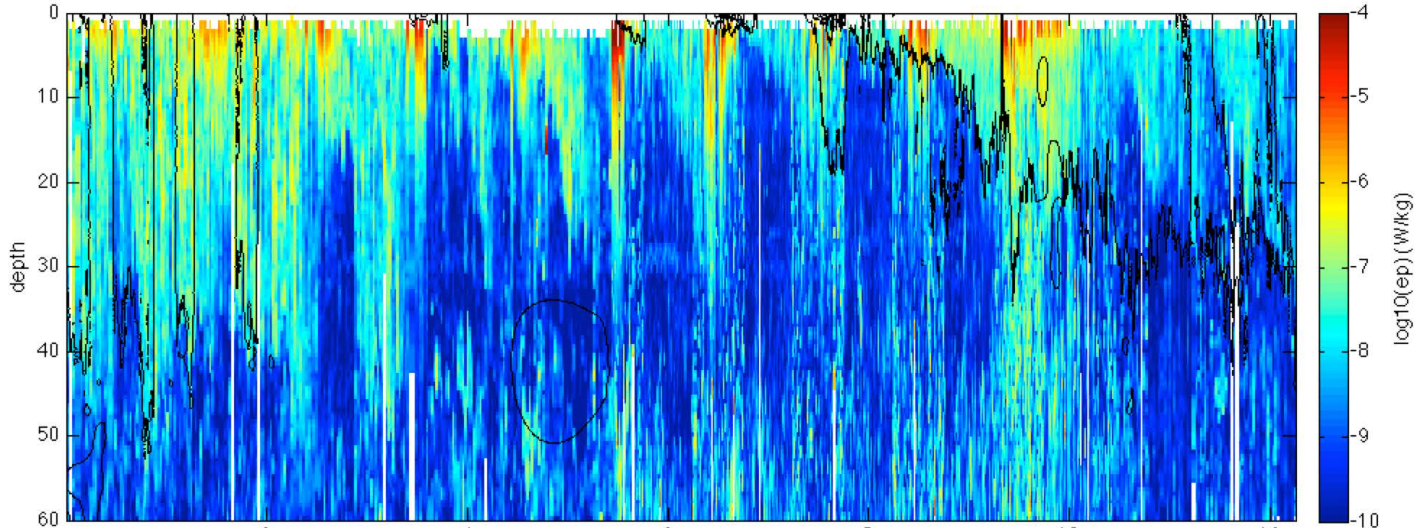




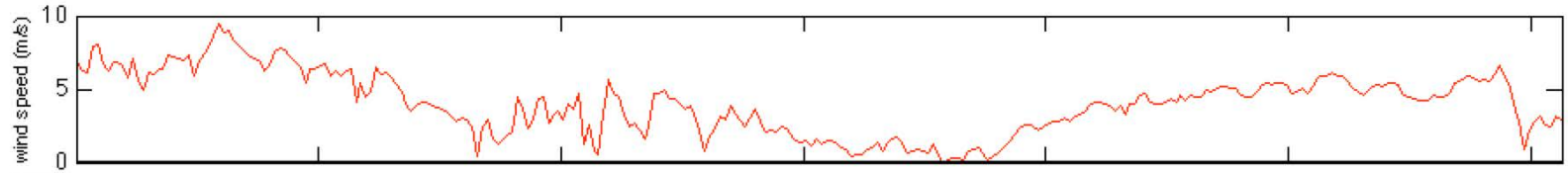
Solar radiation



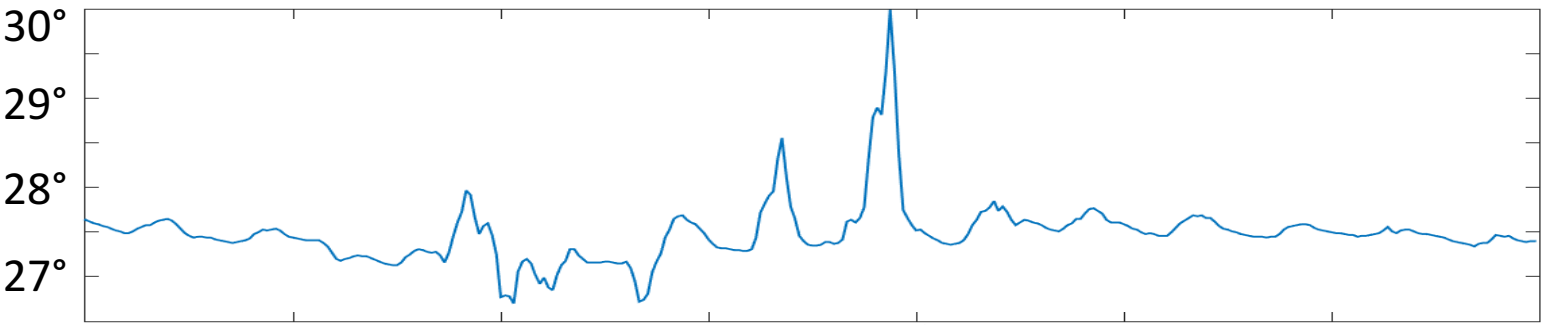
Dissipation



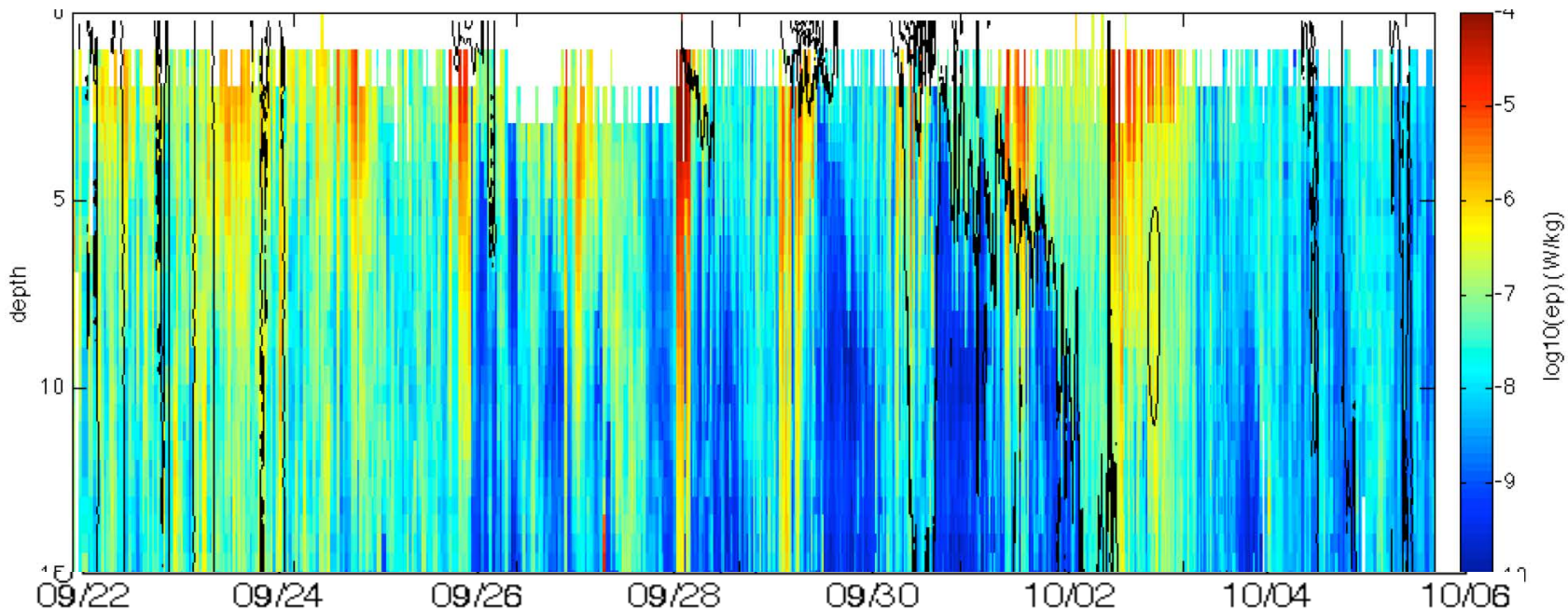
Wind Speed



SST



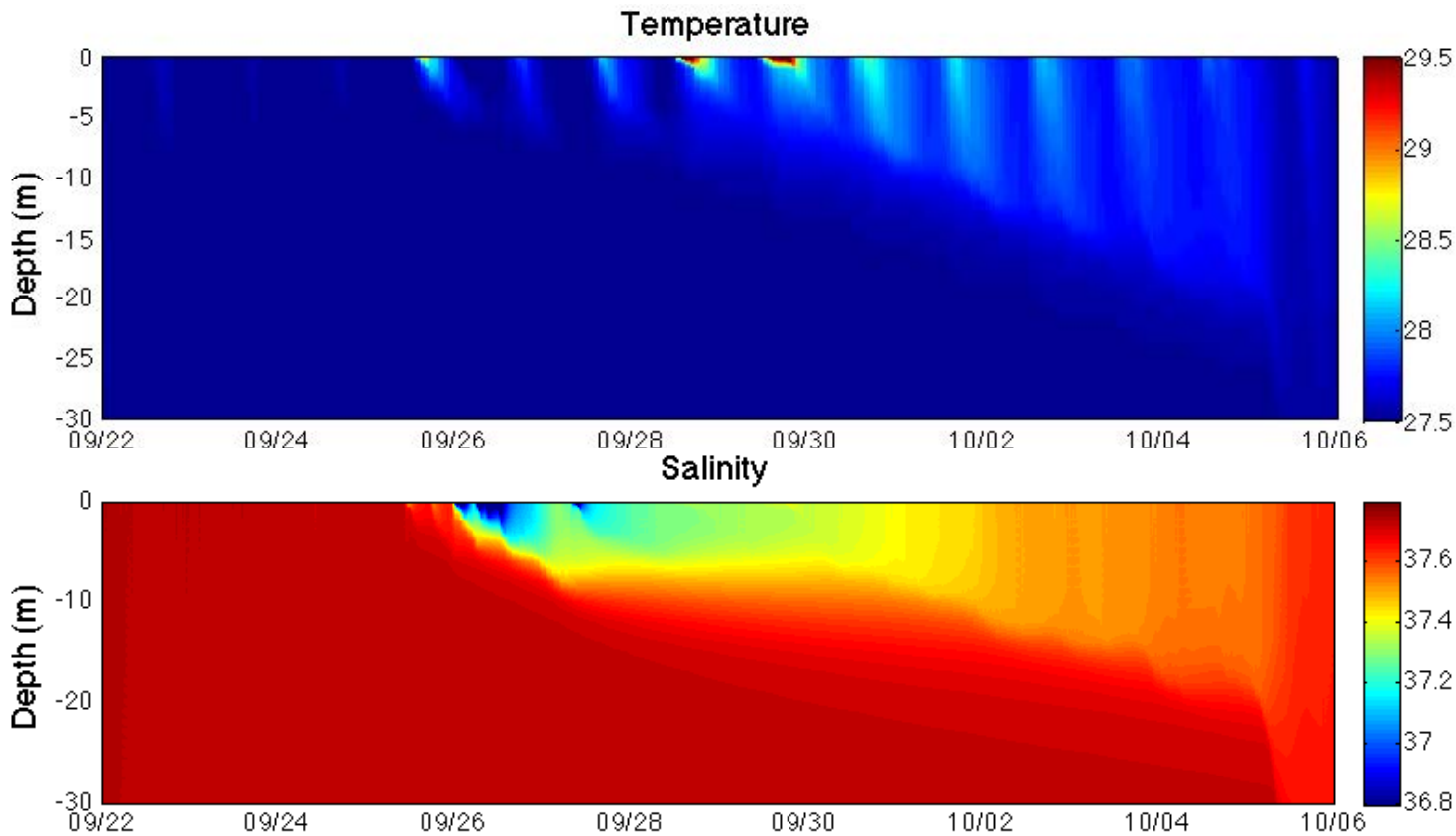
Dissipation of upper 15 m



Does a 1-D ocean model reproduce observed high dissipation?

- Second moment turbulence closure model (Kantha and Clayson, 1994; 2004)
  - Parameterization of increased TKE for:
    - Wave breaking turbulence
    - Langmuir circulation
  - Change in background mixing consistent with strongly stable layer
- Also performed simulations with PWP 1-D model, with similar results

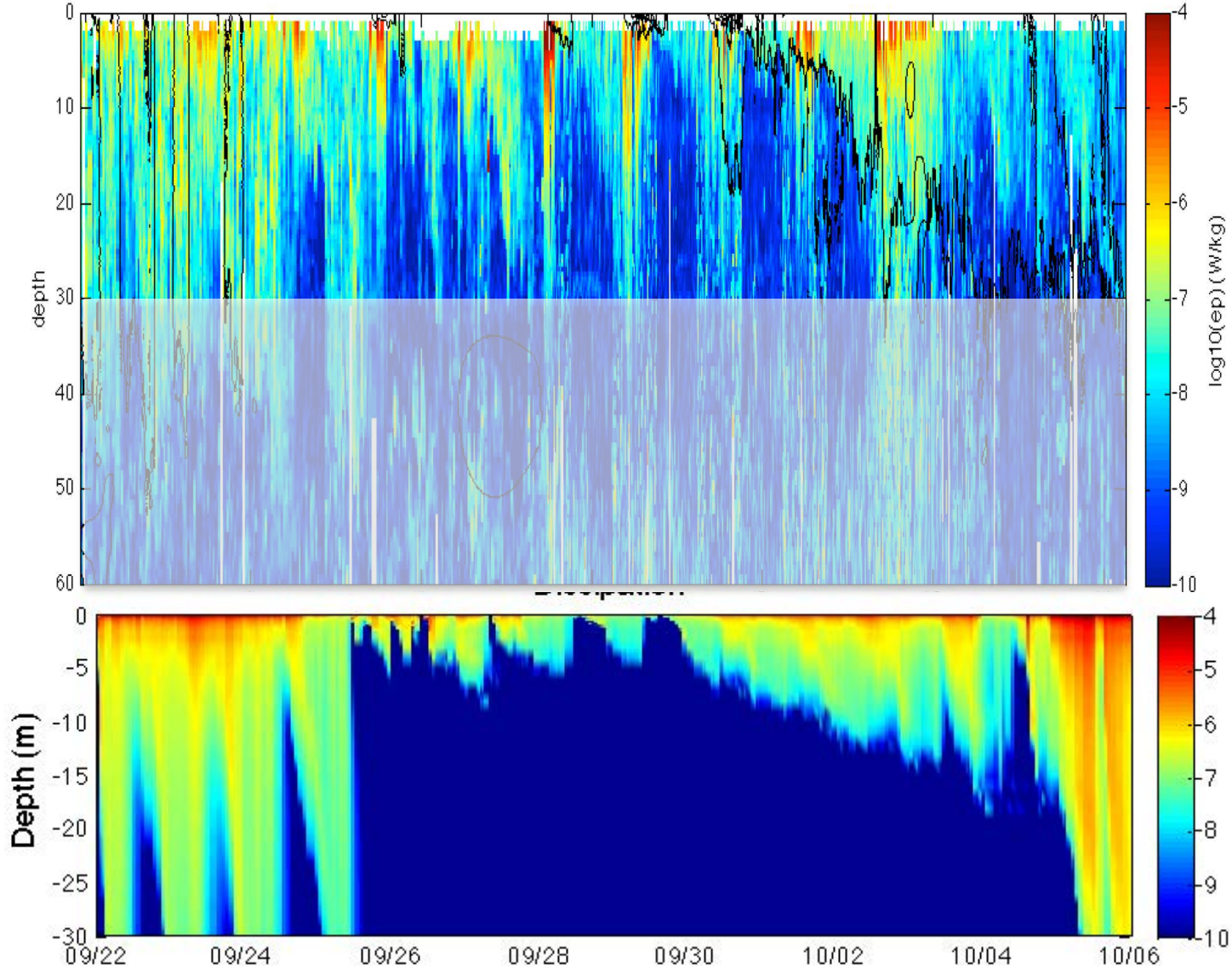
1-D Model Simulations



Observed and modeled dissipation

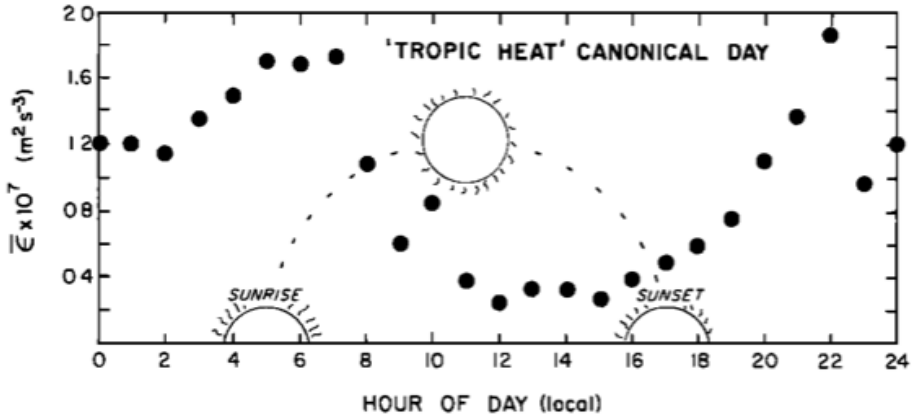
Observed

Modeled



Diurnal cycle of dissipation

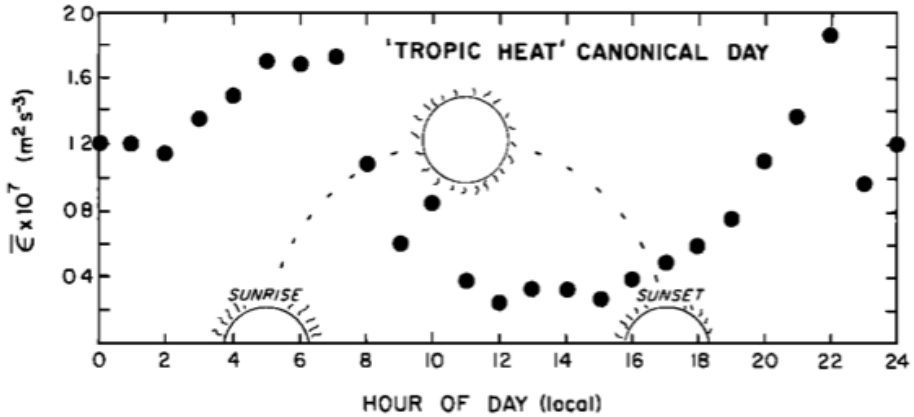
10 to 75 m, Daily wind speeds > 5 m s^{-1}

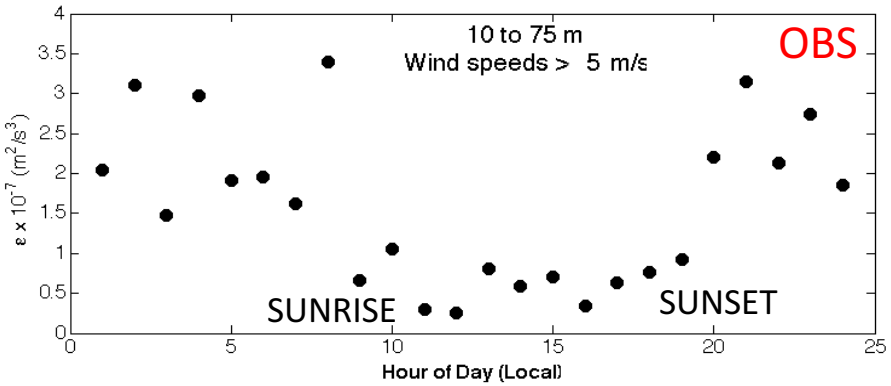


Moum et al. (1989)

Diurnal cycle of dissipation

10 to 75 m, Daily wind speeds > 5 m s^{-1}

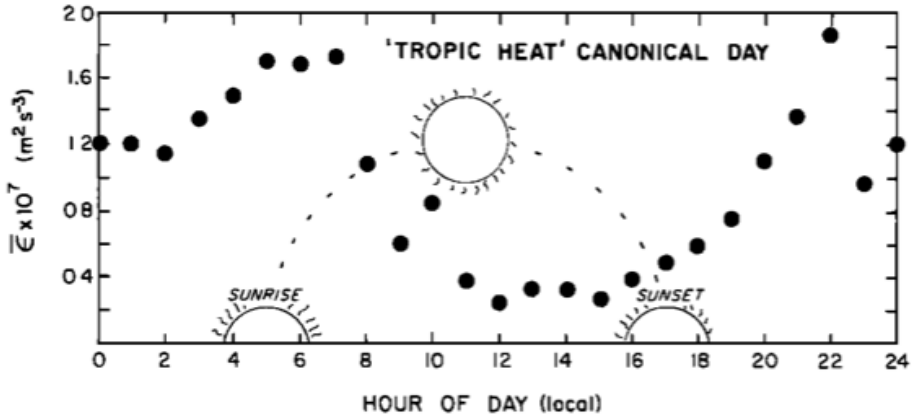


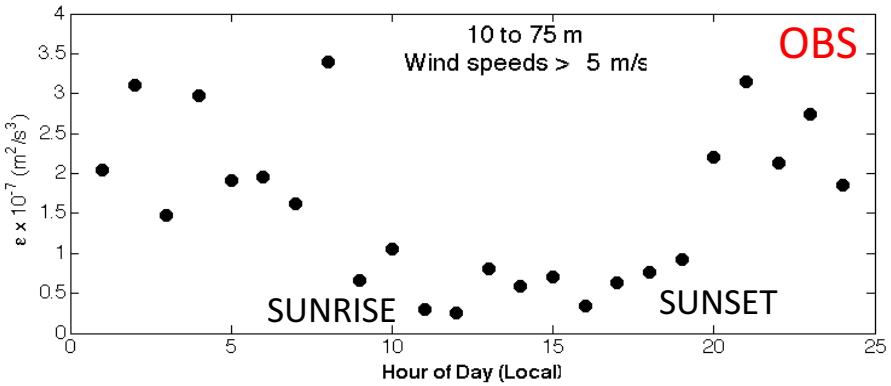


Moum et al. (1989)

Diurnal cycle of dissipation

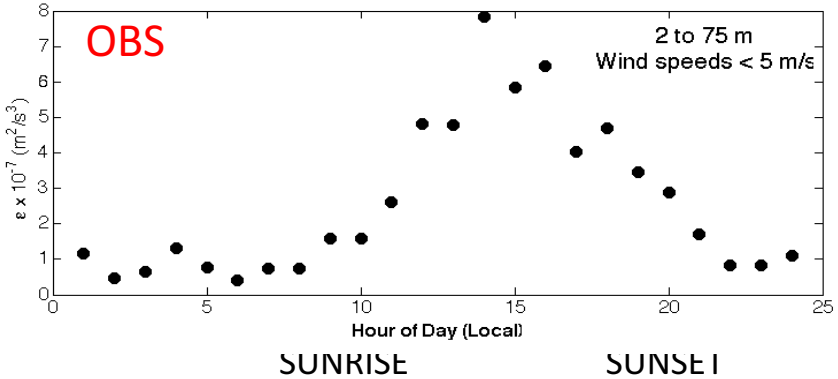
10 to 75 m, Daily wind speeds > 5 m s^{-1}





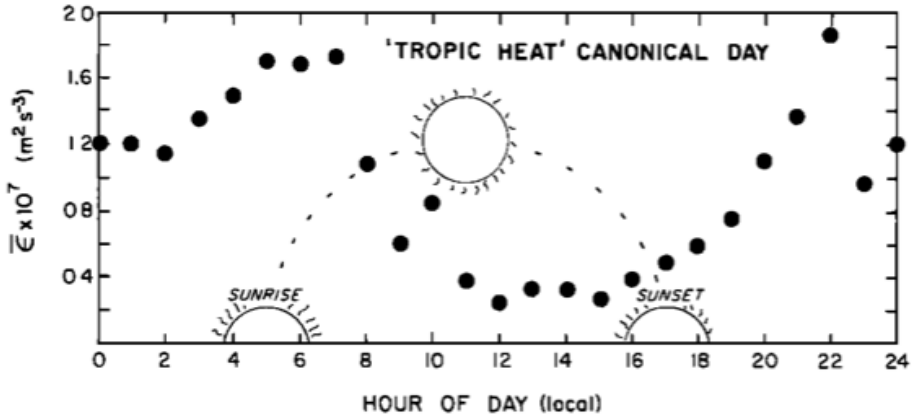
Moum et al. (1989)

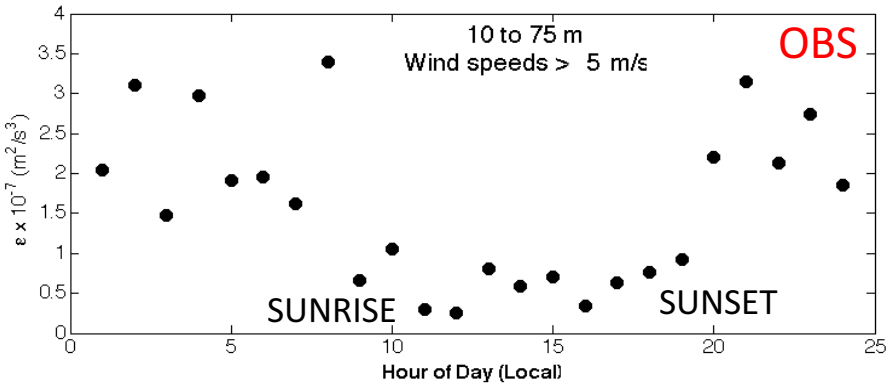
2 to 75 m, Daily wind speeds < 5 m s^{-1}



Diurnal cycle of dissipation

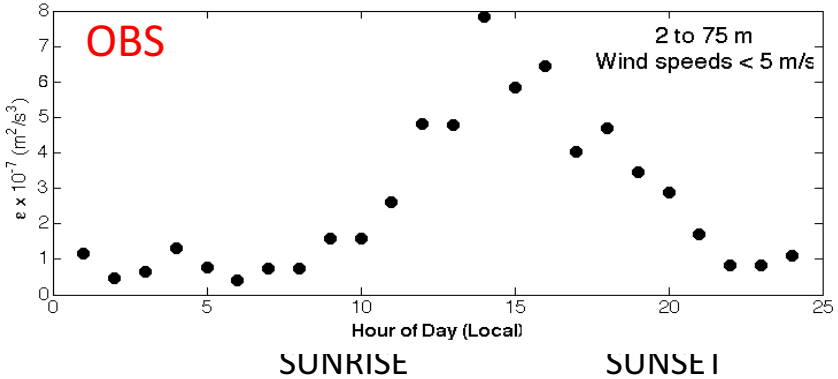
10 to 75 m, Daily wind speeds > 5 m s^{-1}

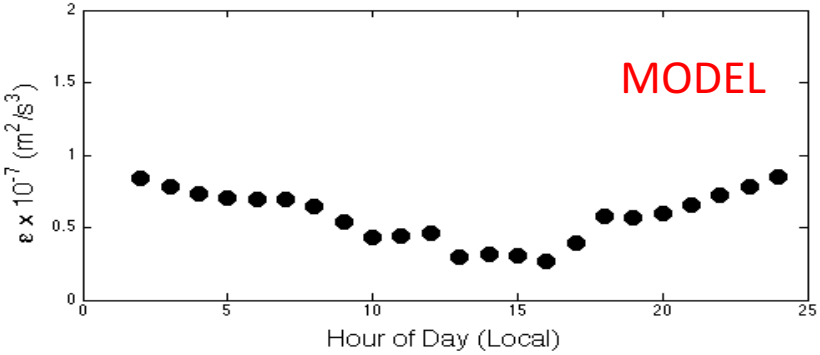


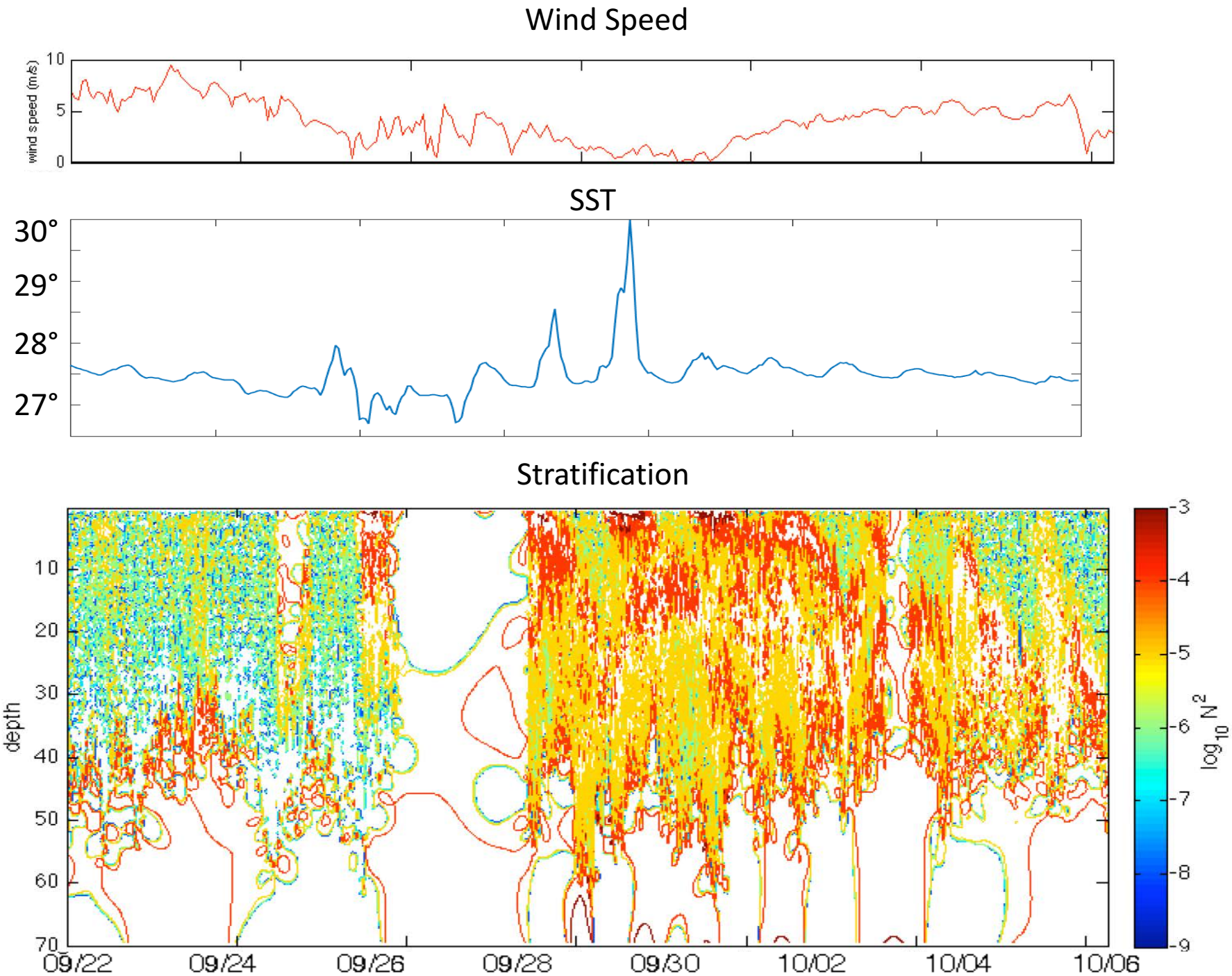


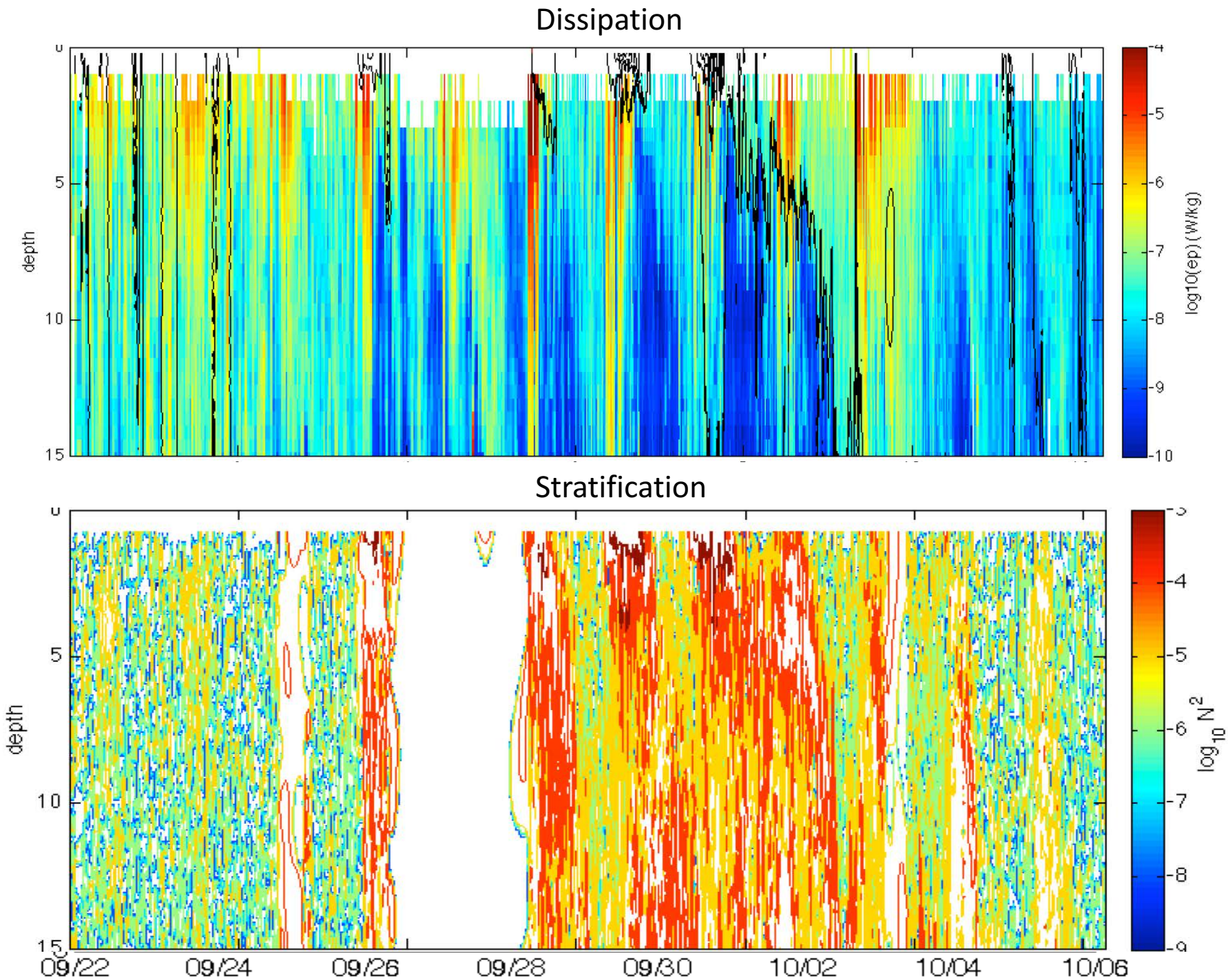
Moum et al. (1989)

2 to 75 m, Daily wind speeds < 5 m s^{-1}

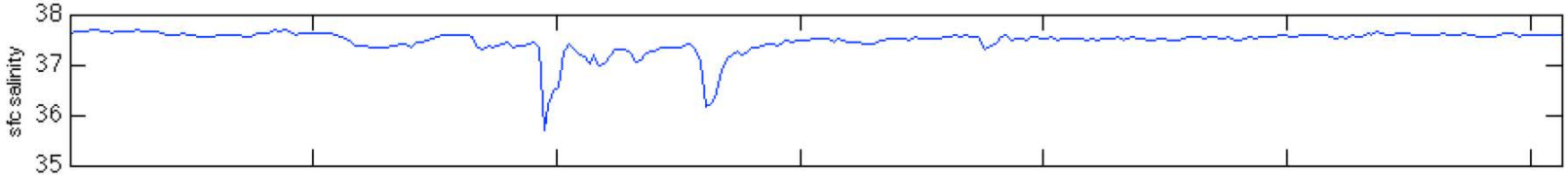


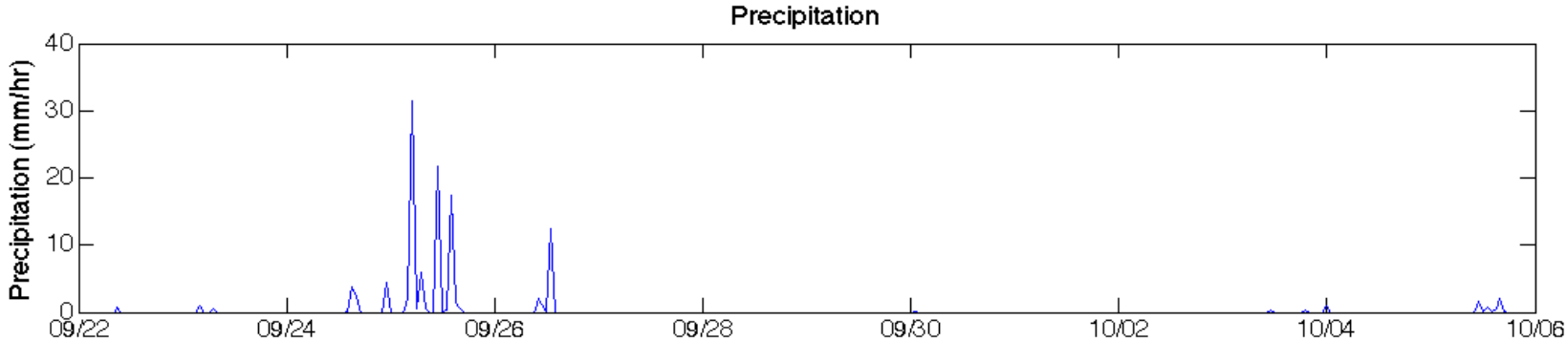



Wind Speed
wind speed (m/s)
10
5
0
SST
30°
29°
28°
27°
Stratification
depth
10
20
30
40
50
60
70
09/22
09/24
09/26
09/28
09/30
10/02
10/04
10/06
-3
-4
-5
-6
-7
-8
-9
$\log_{10} N^2$

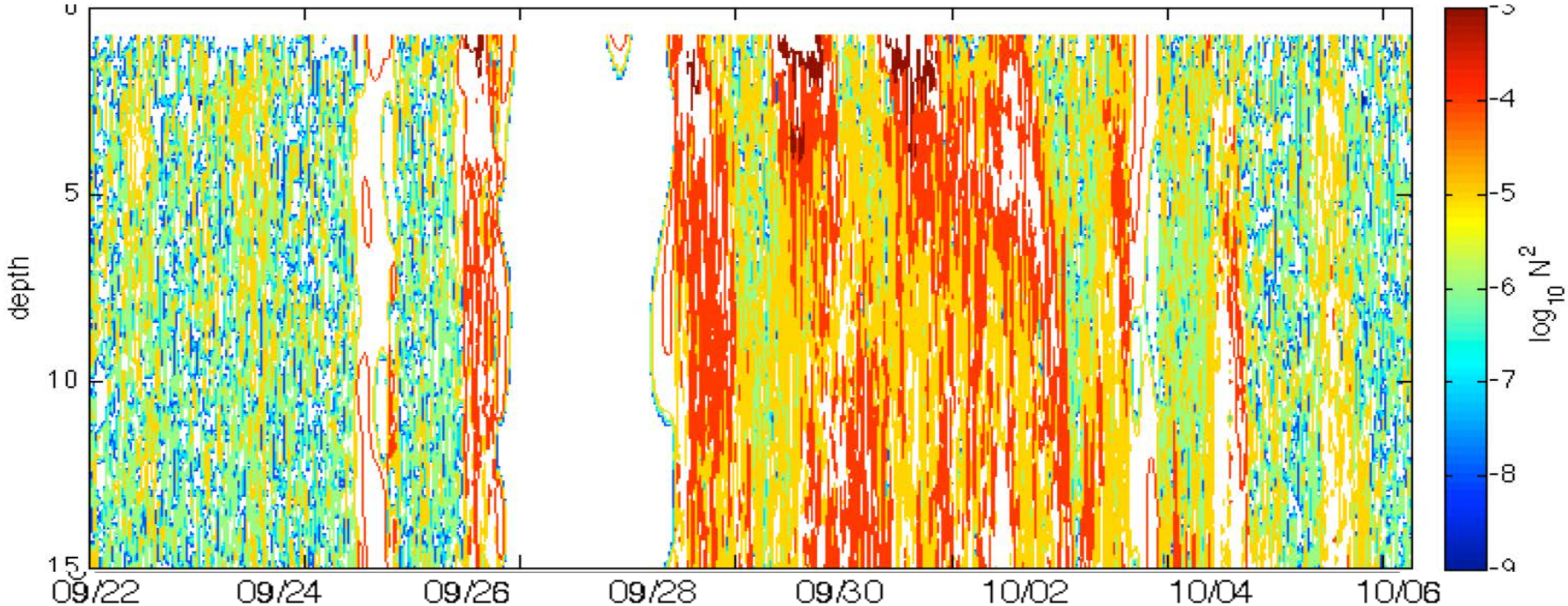

Dissipation
depth
0
5
10
15
log10(ep) (W/kg)
-4
-5
-6
-7
-8
-9
-10
Stratification
depth
0
5
10
15
$\log_{10} N^2$
-4
-5
-6
-7
-8
-9
09/22
09/24
09/26
09/28
09/30
10/02
10/04
10/06

Surface salinity





Stratification

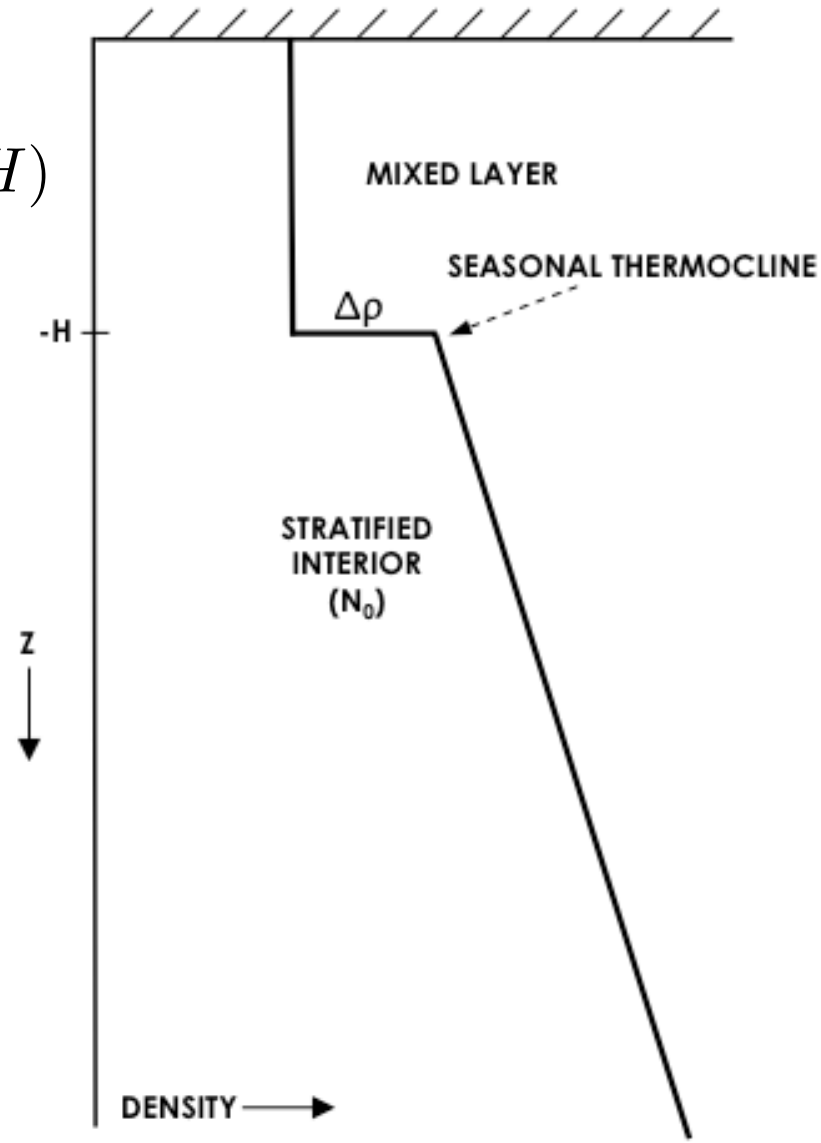


Idealized profile of the upper ocean (D'Asaro, 1978)

$$N^2(z) = N_0^2 \mathcal{H}(-z-H) + \frac{g'_H}{\epsilon}\delta(z+H)$$

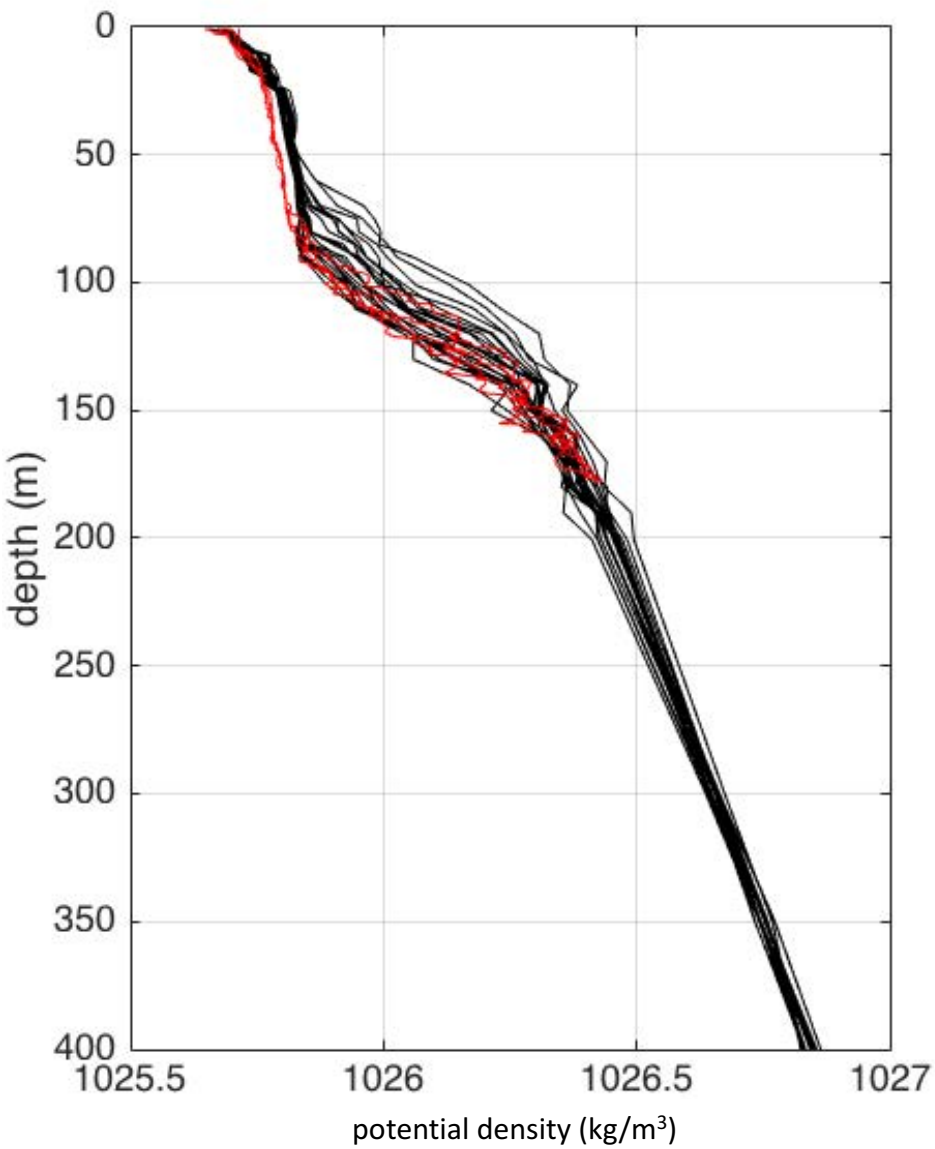
Heaviside function

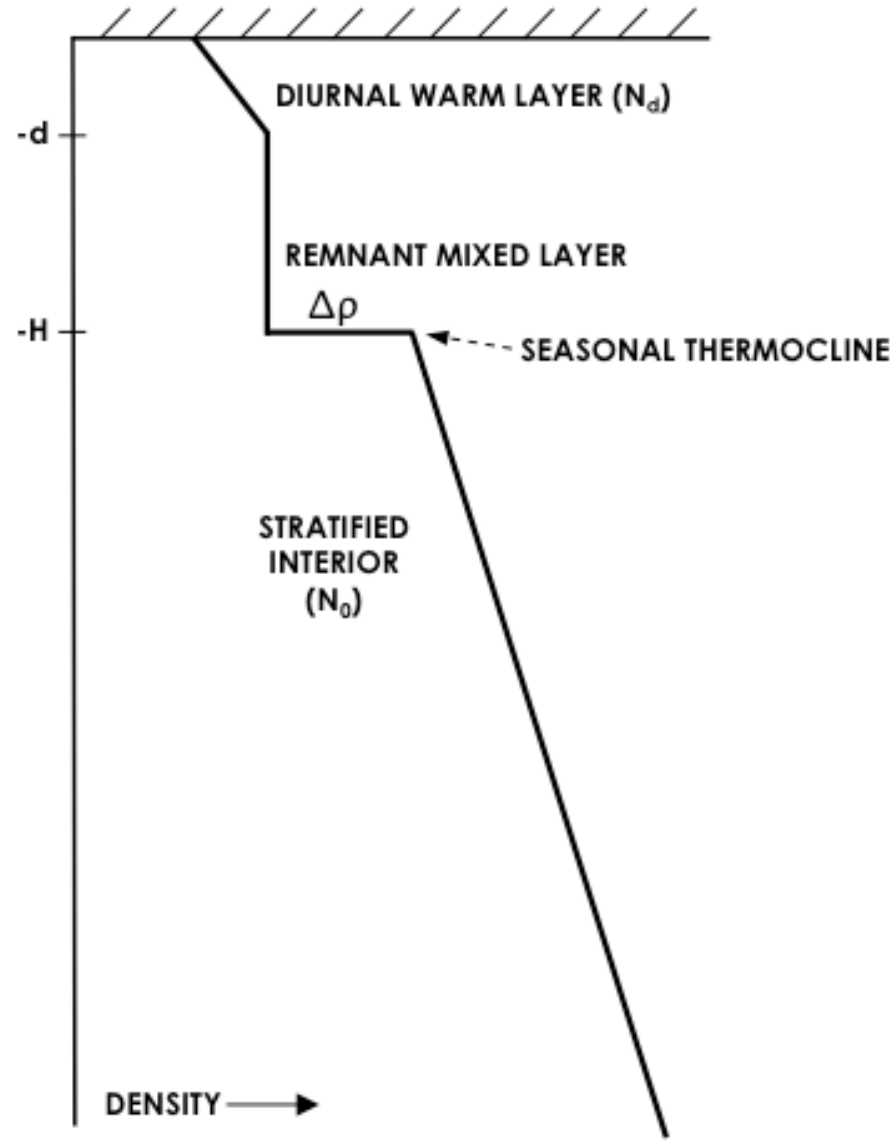
Dirac delta function

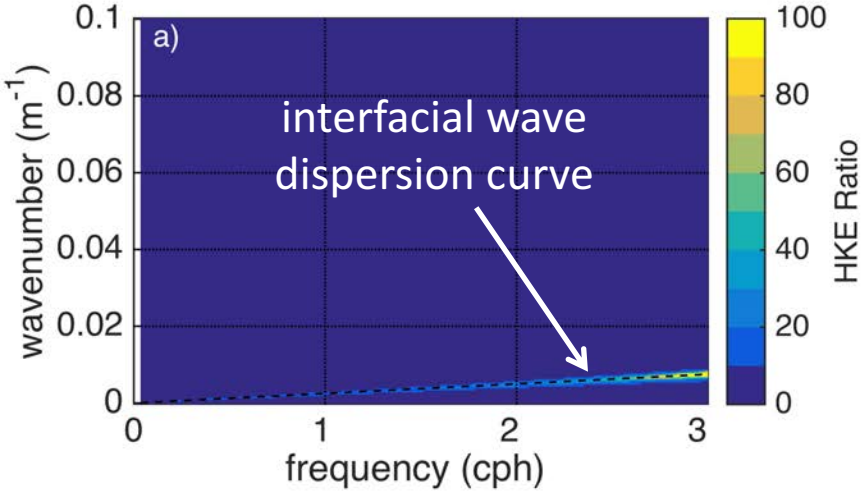


- Solution for an internal wave in the mixed layer and stratified interior.
- Use surface boundary condition, and matching condition at seasonal thermocline.
- Compare average energy in each layer.

Addition of a Diurnal Warm Layer

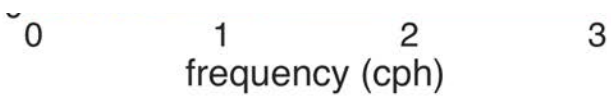


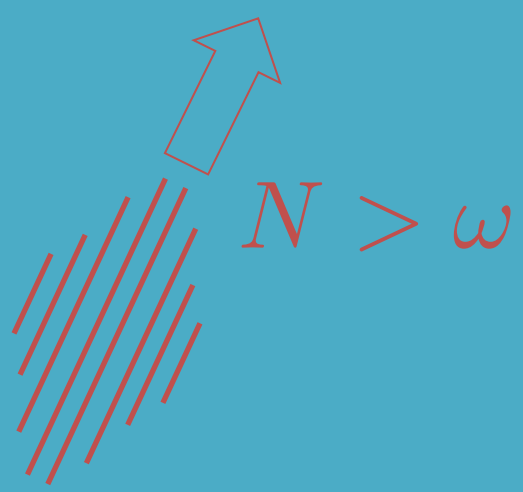




$$\frac{\langle U_{ML}^2 \rangle}{\langle U_{SI}^2 \rangle} = 2\left[\frac{N_0^2 - \omega^2}{\omega^2 - f^2}\alpha^2 H^2 + \left(1 - \frac{\alpha^2}{\omega^2 - f^2}V_H^2\right)^2\right]^{-1}$$

1 kg/m^3 density jump at seasonal thermocline

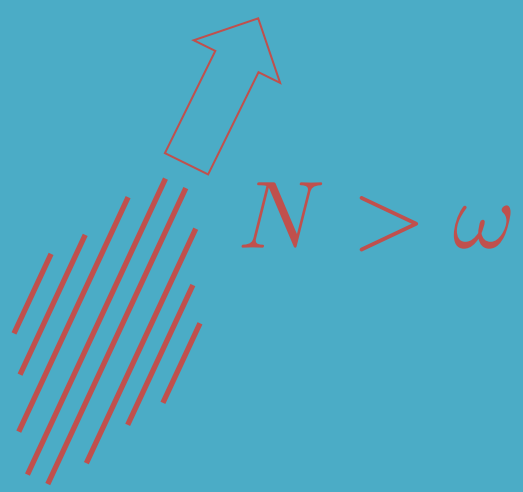




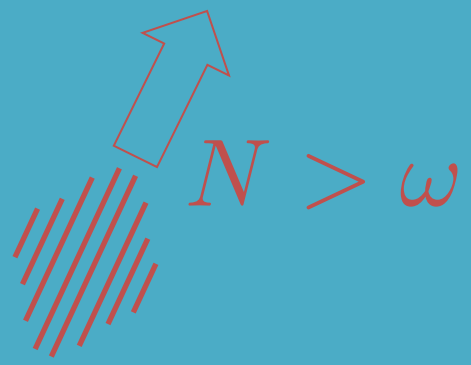
Internal wave tunneling

$N < \omega$

Internal waves exponentially decay in regions where the **buoyancy frequency** is less than the frequency of the wave.

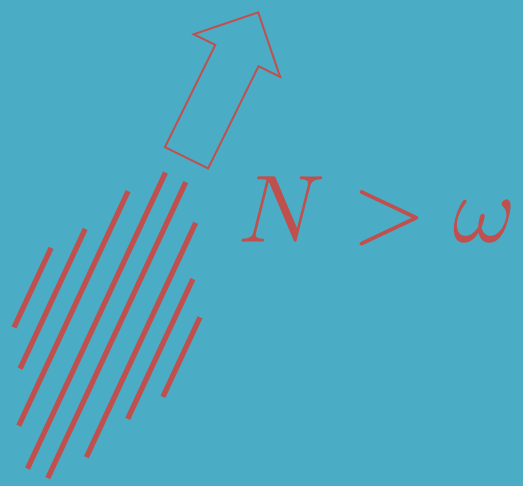


Internal wave tunneling



$N < \omega$

Internal waves exponentially decay in regions where the **buoyancy frequency** is less than the frequency of the wave.



Internal wave tunneling

Ratio of HKE with DWL

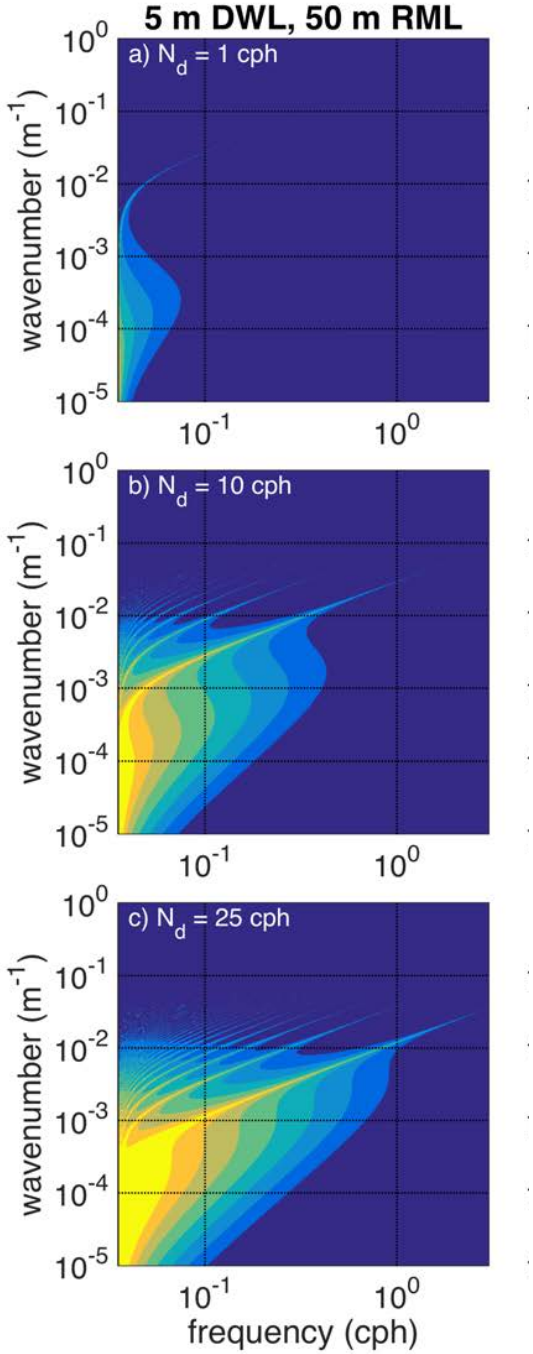
Compare the energy of the DWL to the energy of the stratified interior.

$$\frac{\langle U_{ML}^2 \rangle}{\langle U_{SI}^2 \rangle} = 2\left[m^2 H^2 + \left(1 - \frac{\alpha^2}{\omega^2 - f^2} g' H\right)^2\right]^{-1}$$

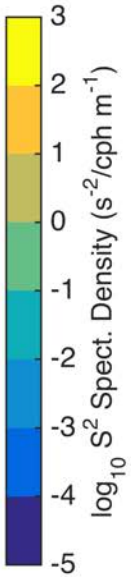
$$\boxed{\frac{\langle U_{DWL}^2 \rangle}{\langle U_{SI}^2 \rangle} = \frac{2n^2 d^2 + nd\sin(2nd)}{2\sin^2(nd)}\left[m^2 H_*^2 + \left(\mu d_* - \frac{\alpha^2}{\omega^2 - f^2} g' H_*\right)^2\right]^{-1}}$$

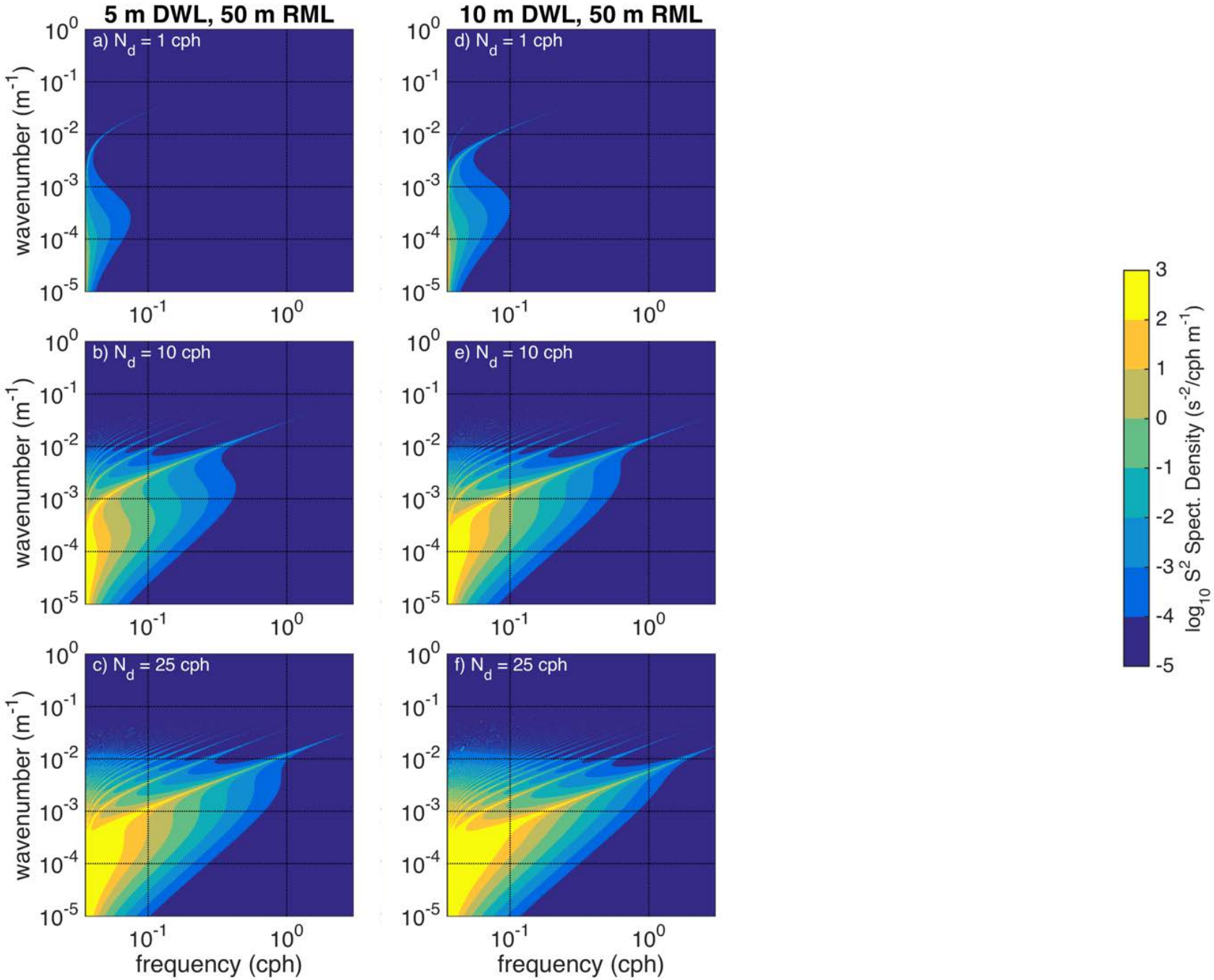
0.05ºC
10 m

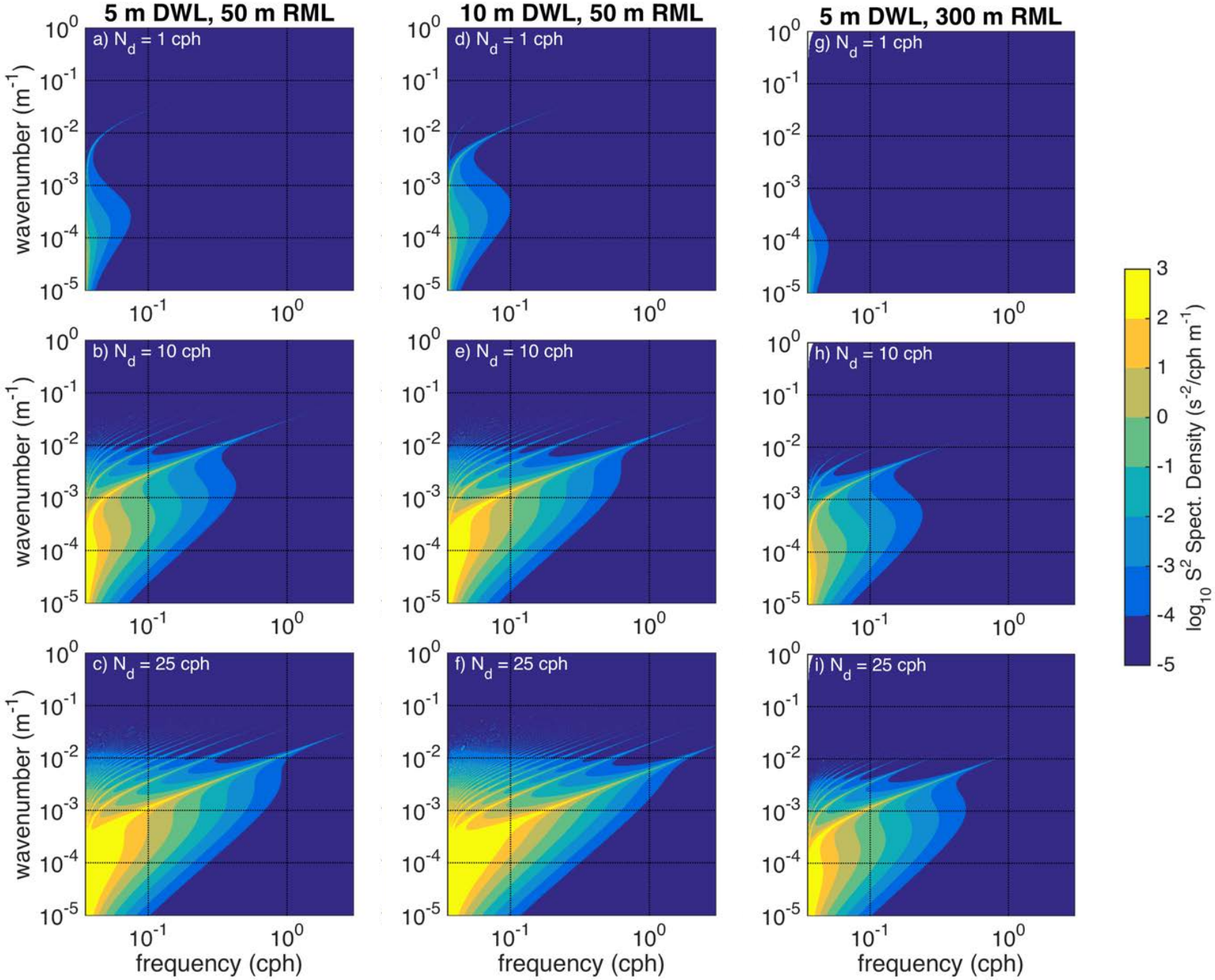
1ºC
1m



Waves propagating from the deep ocean tunnel through the remnant mixed layer and generate strong shear across the diurnal warm layer.

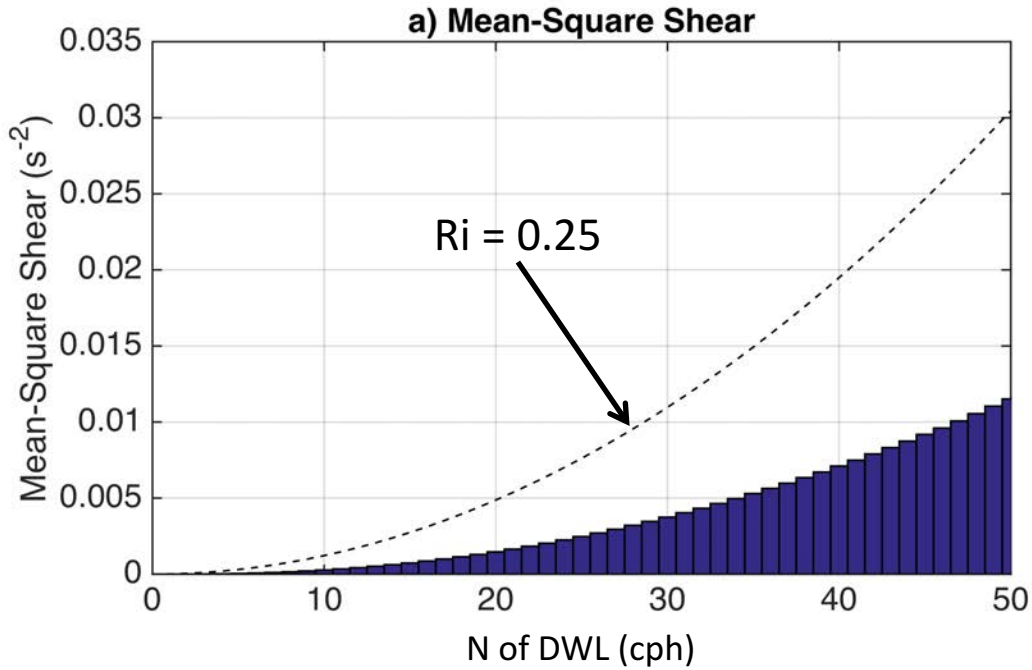



5 m DWL, 50 m RML
10 m DWL, 50 m RML
a) N_d = 1 cph
b) N_d = 10 cph
c) N_d = 25 cph
d) N_d = 1 cph
e) N_d = 10 cph
f) N_d = 25 cph
wavenumber (m^-1)
frequency (cph)
log10 S^2 Spect. Density (s^-2/cph m^-1)
0.05ºC
10 m
1ºC
1m



0.05ºC
10 m

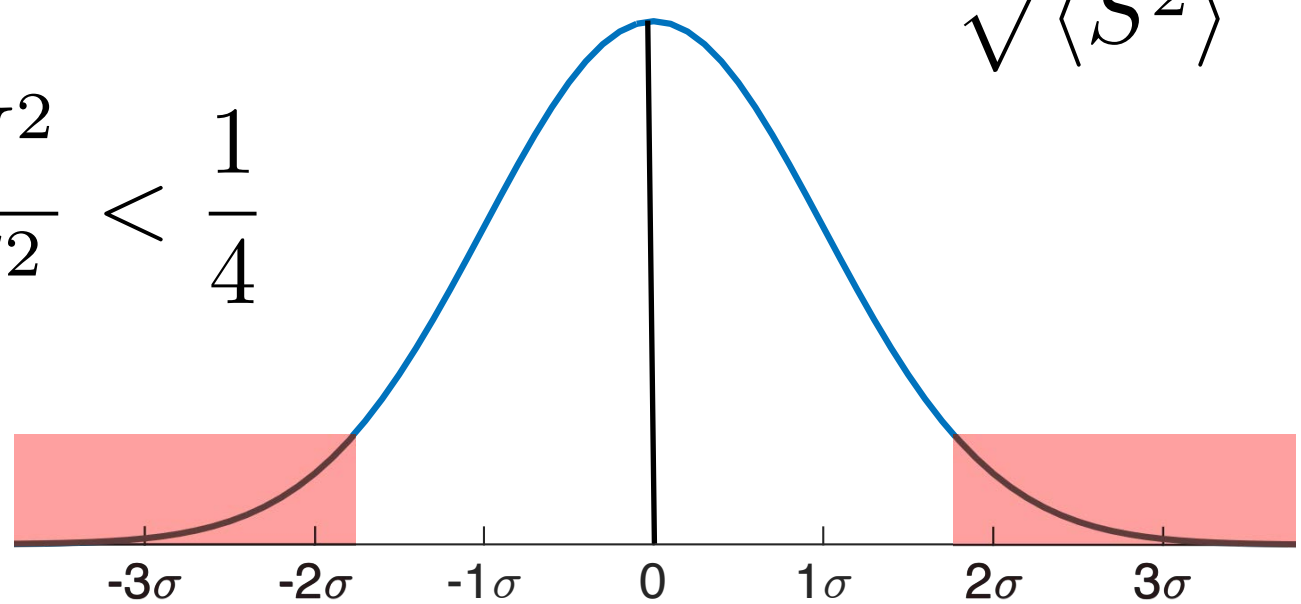
1ºC
1m

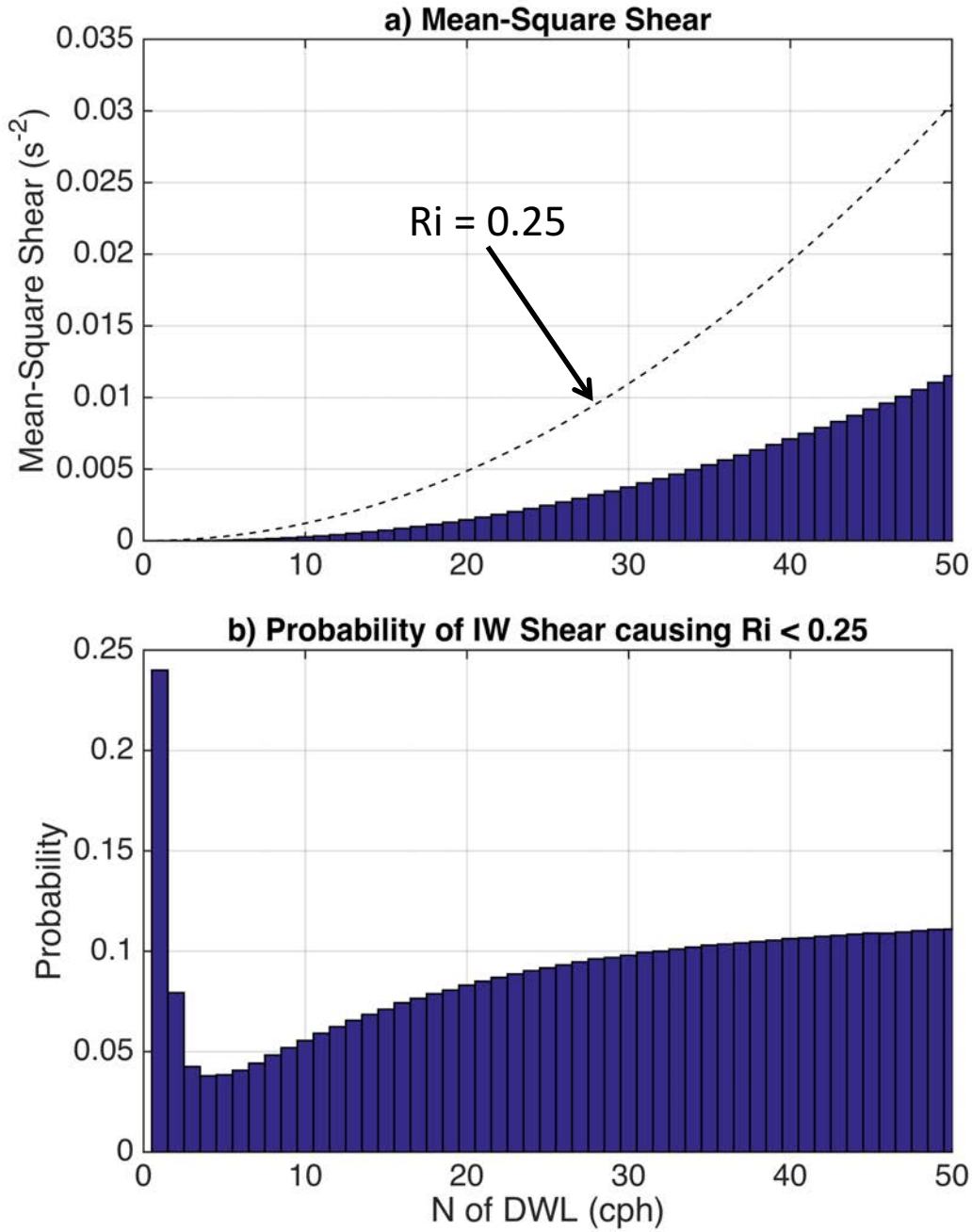


Shear increases with N

$$z = \sqrt{4}\frac{N_{\mathrm{DWL}}}{\sqrt{\langle S^2 \rangle}}$$

$$Ri = \frac{N^2}{S^2} < \frac{1}{4}$$

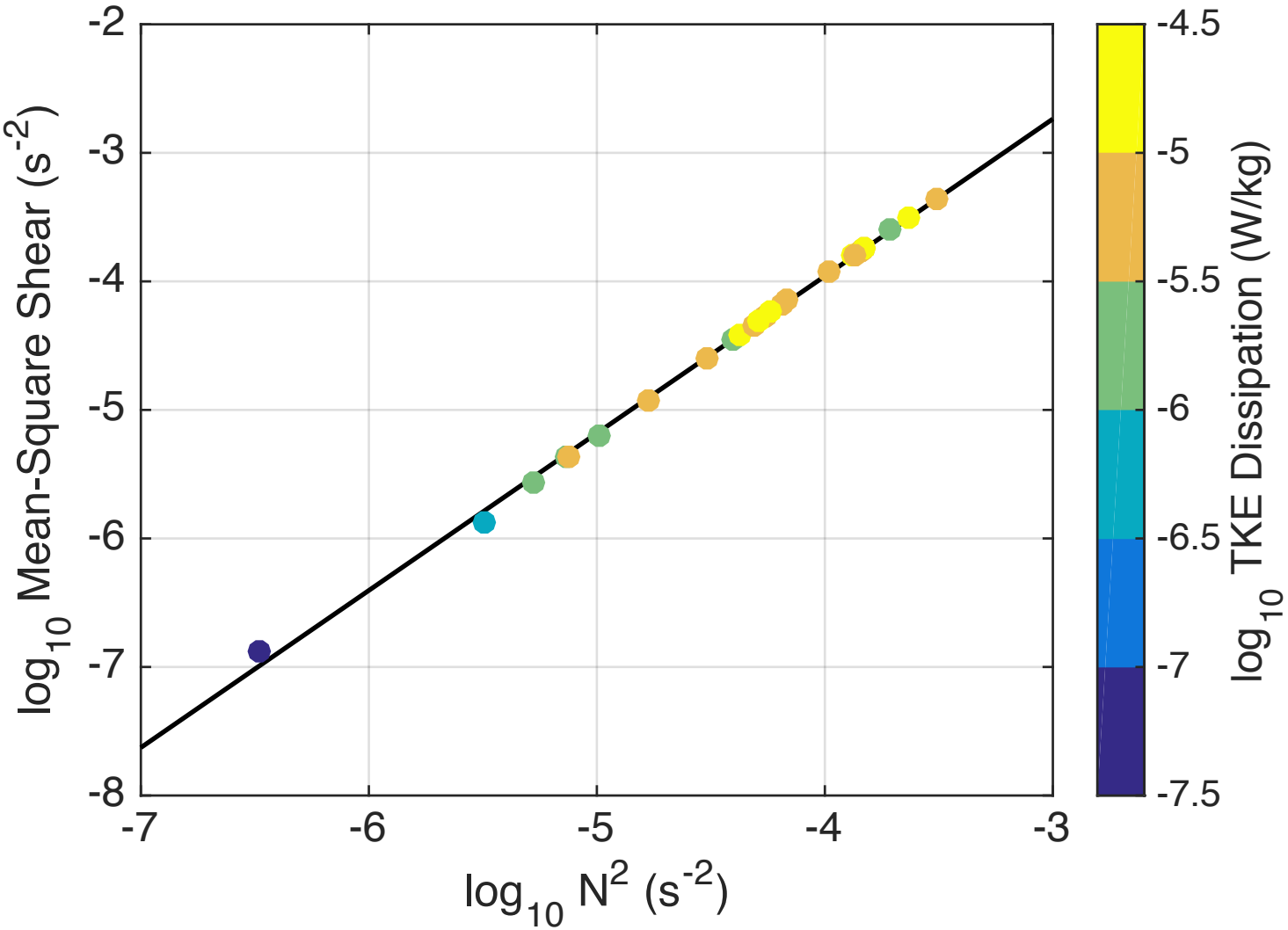




Shear increases with N

As does the probability of IW causing Ri < 0.25

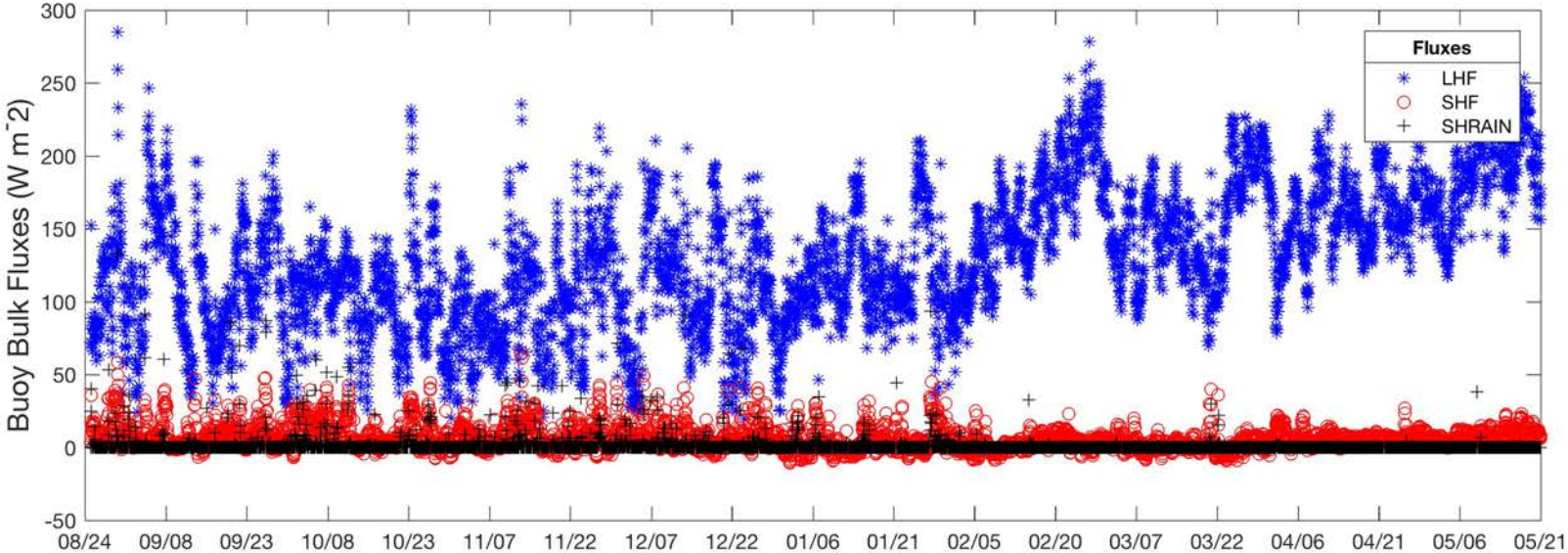
N_{DWL} increases,
Shear increases,
TKE dissipation increases



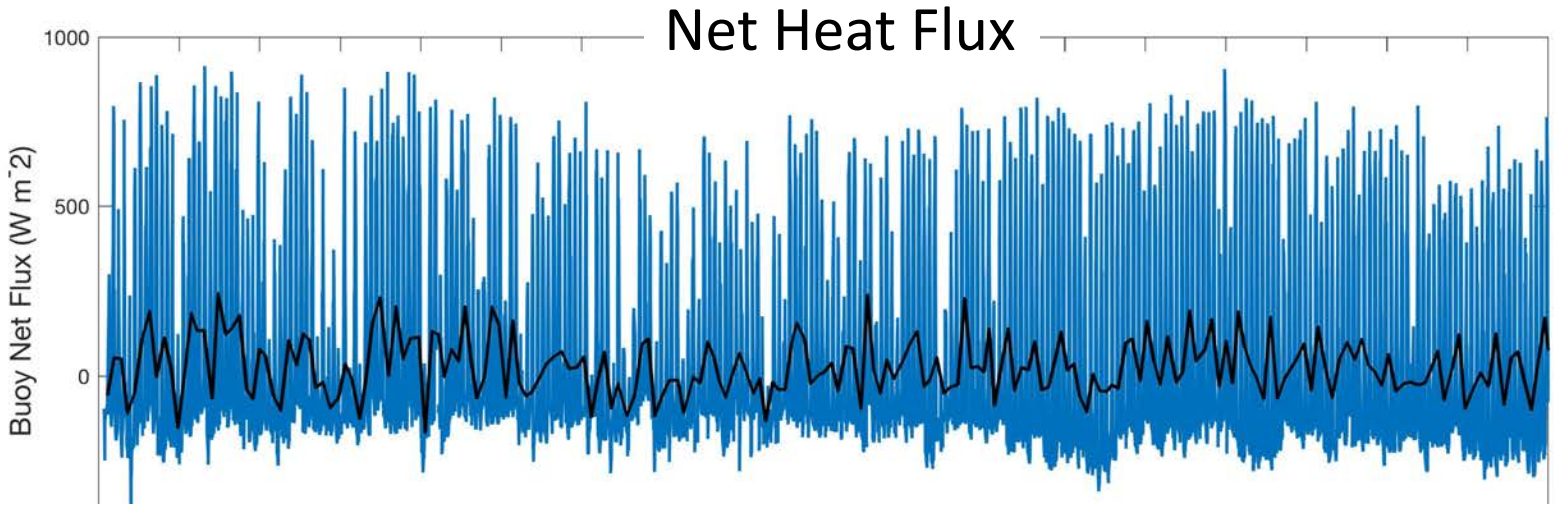
SPURS-2 Buoy Variability

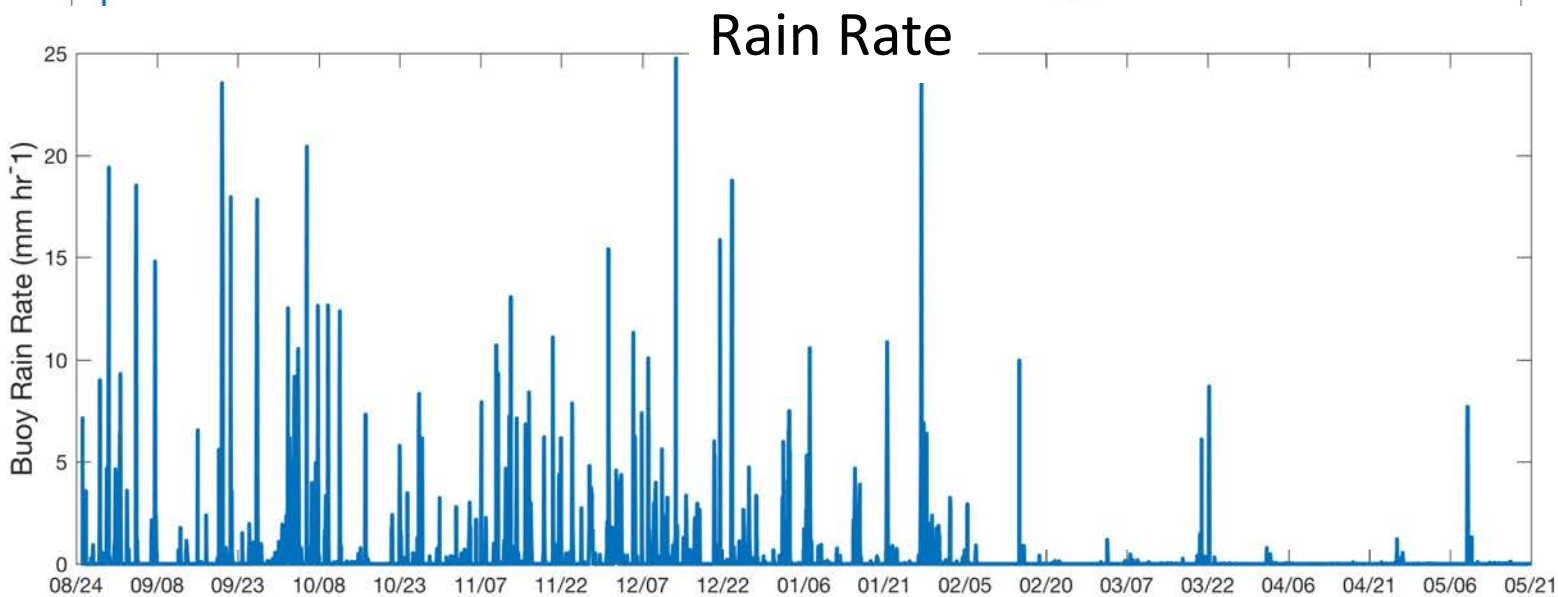
- Real-time data available from WHOI UOP web site
- Hourly bulk parameters
  - Used COARE 3.5 to calculate turbulent fluxes
- SST, SSS (1 m) also available

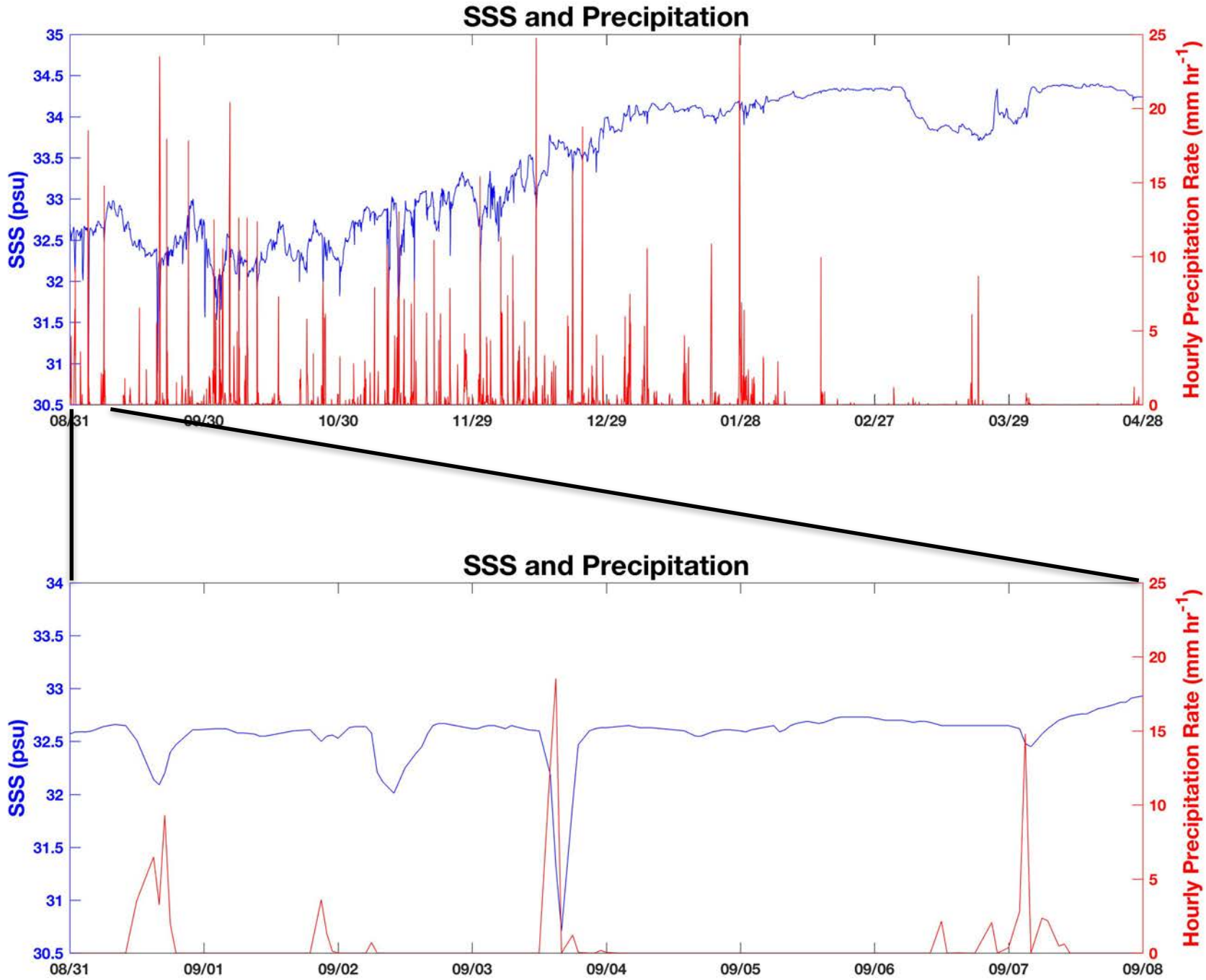
Turbulent Heat Fluxes



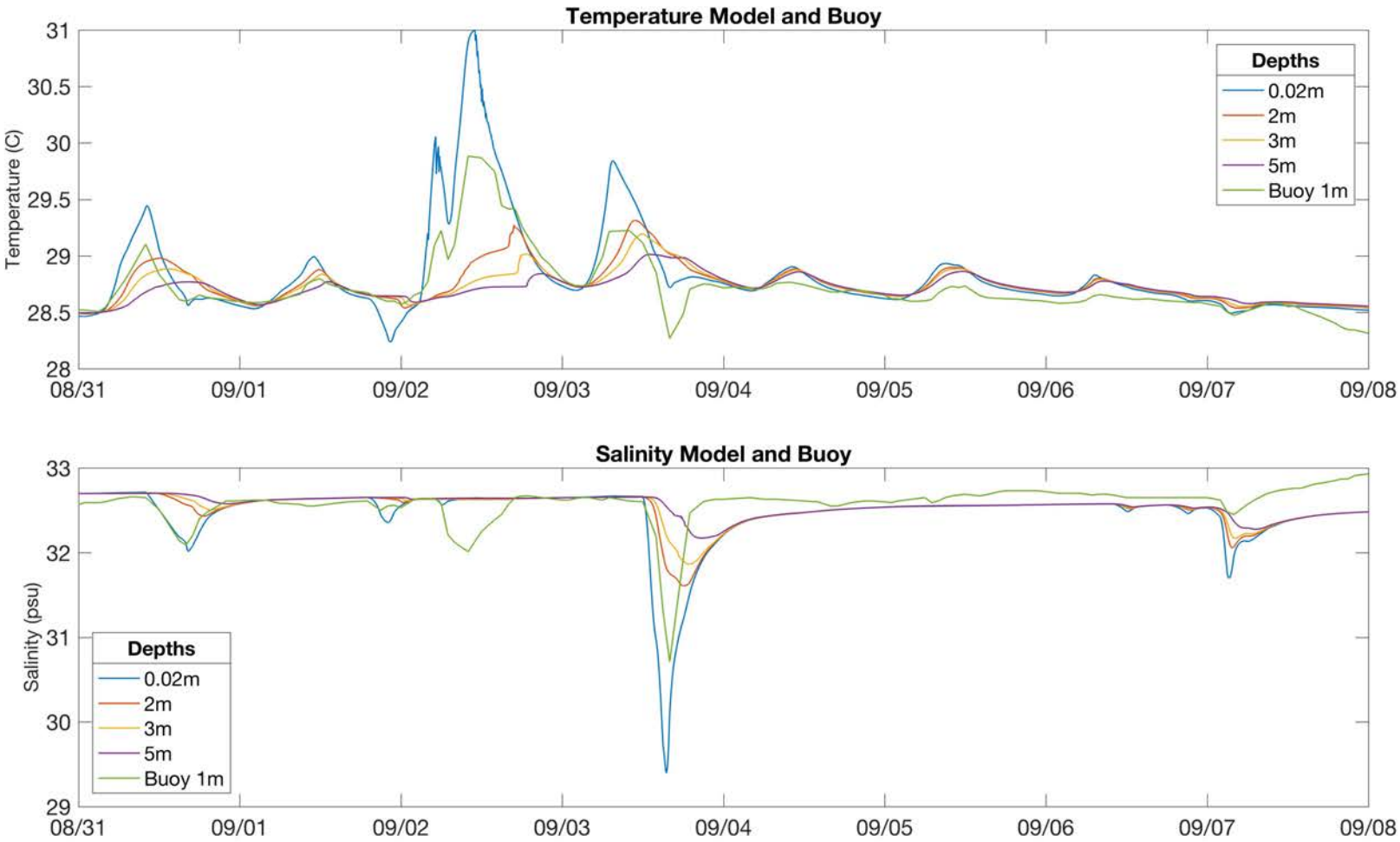
SPURS-2 Buoy Data



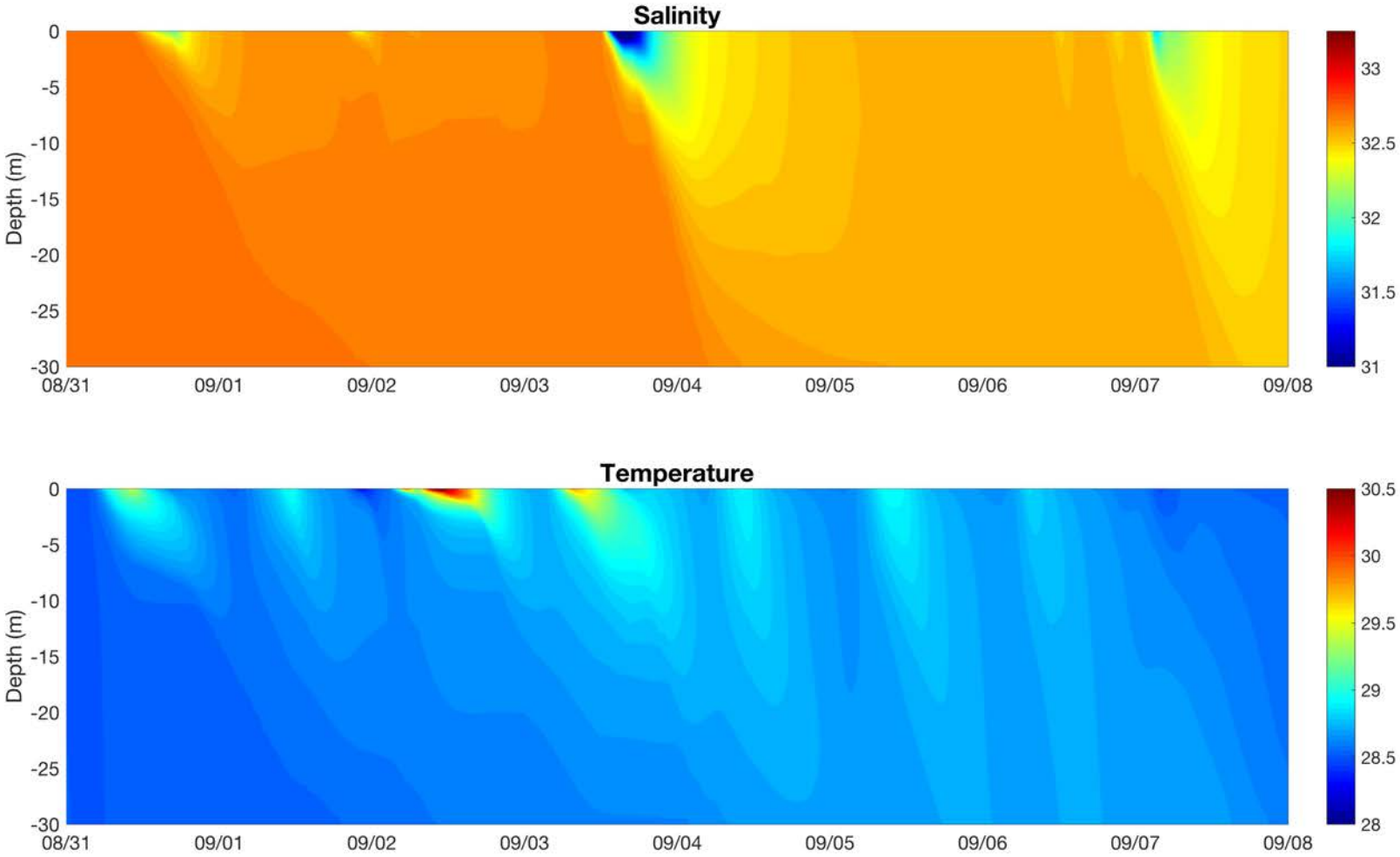



SSS and Precipitation
SSS (psu)
Hourly Precipitation Rate (mm hr^{-1})
35
34.5
34
33.5
33
32.5
32
31.5
31
30.5
25
20
15
10
5
0
08/31
09/30
10/30
11/29
12/29
01/28
02/27
03/29
04/28
SSS and Precipitation
SSS (psu)
Hourly Precipitation Rate (mm hr^{-1})
34
33.5
33
32.5
32
31.5
31
30.5
25
20
15
10
5
0
08/31
09/01
09/02
09/03
09/04
09/05
09/06
09/07
09/08

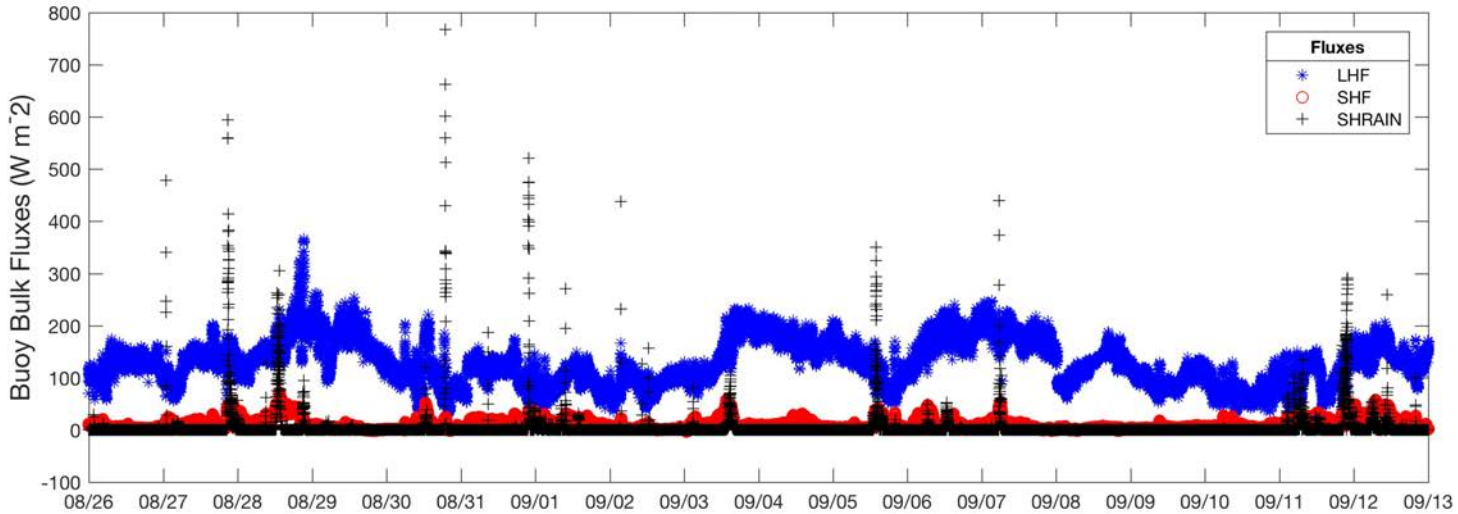
Surface temperature and salinity

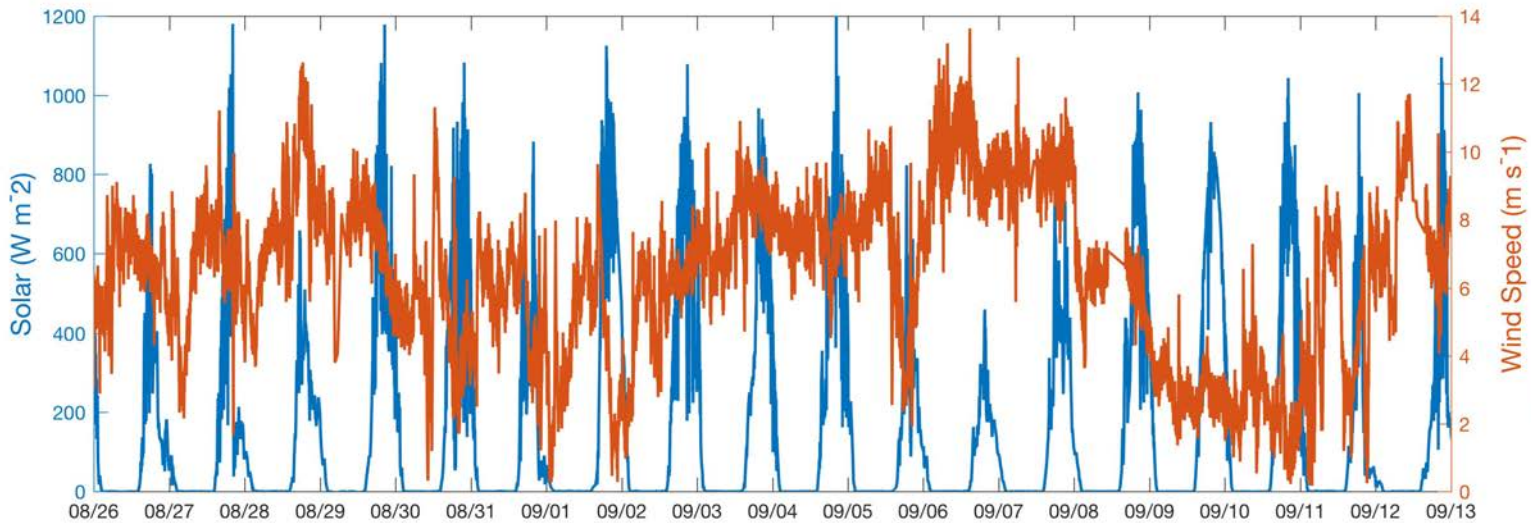


Modeled upper ocean variability

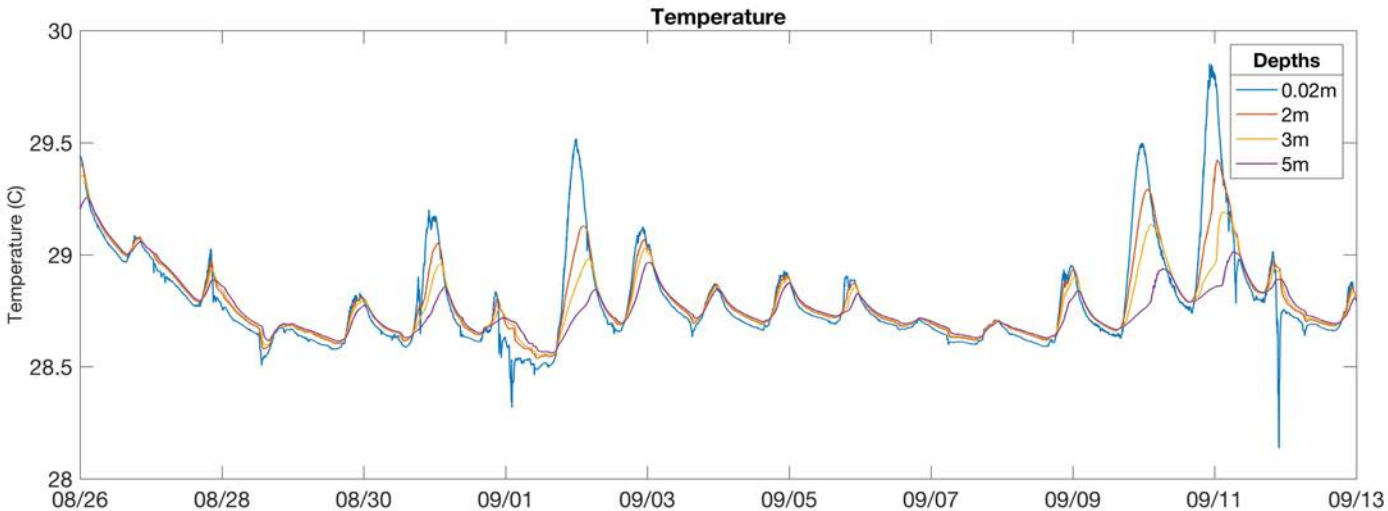


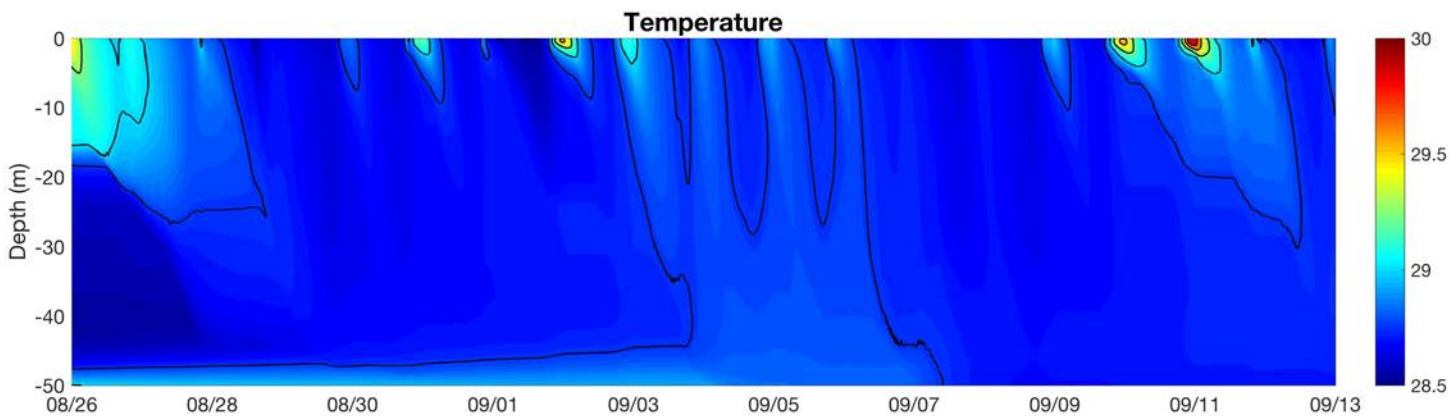
Ship fluxes


Buoy Bulk Fluxes (W m^-2)
Fluxes
LHF
SHF
SHRAIN
800
700
600
500
400
300
200
100
0
-100
08/26
08/27
08/28
08/29
08/30
08/31
09/01
09/02
09/03
09/04
09/05
09/06
09/07
09/08
09/09
09/10
09/11
09/12
09/13

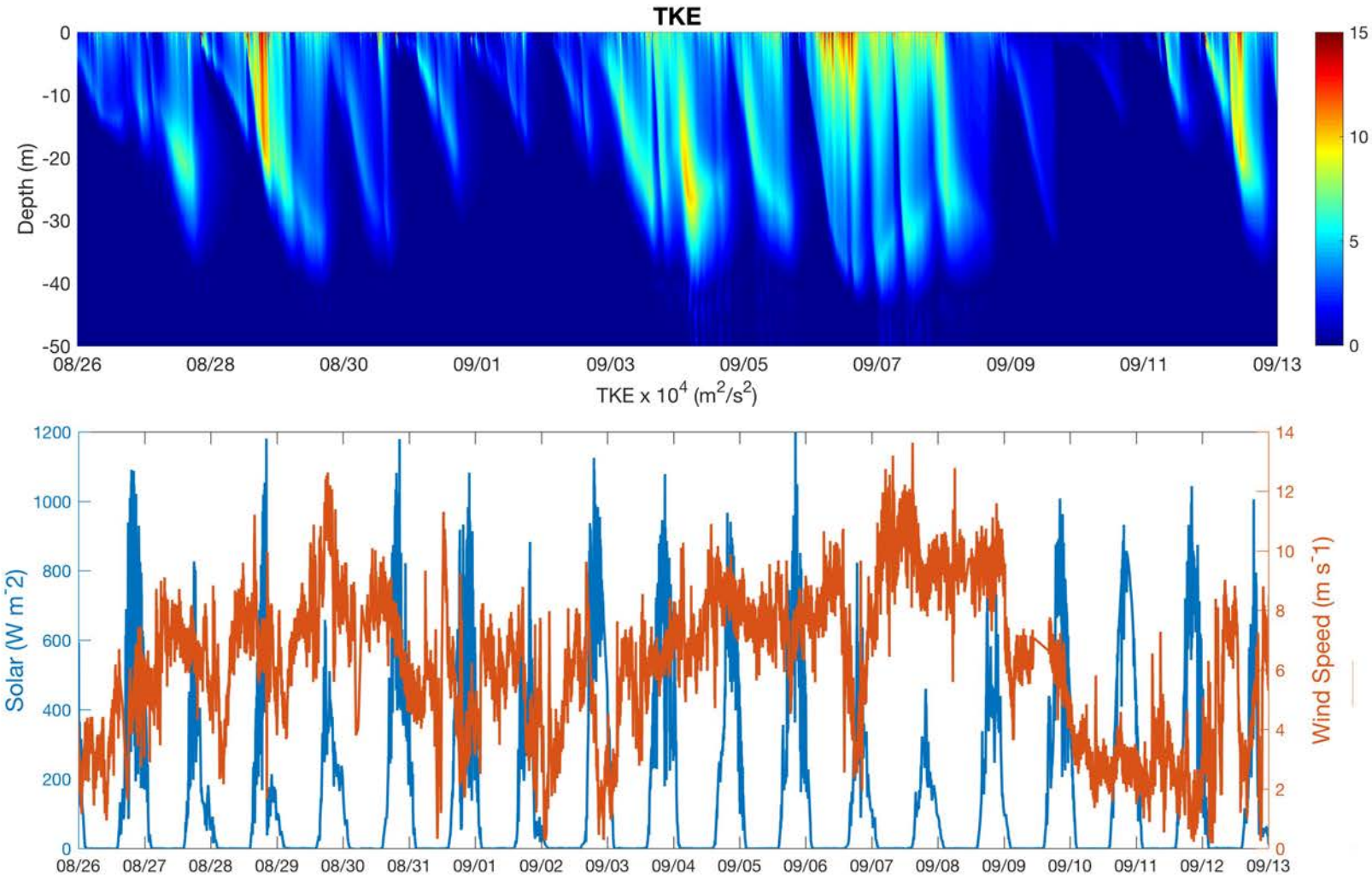

Solar (W m^-2)
Wind Speed (m s^-1)
1200
1000
800
600
400
200
0
14
12
10
8
6
4
2
0
08/26
08/27
08/28
08/29
08/30
08/31
09/01
09/02
09/03
09/04
09/05
09/06
09/07
09/08
09/09
09/10
09/11
09/12
09/13

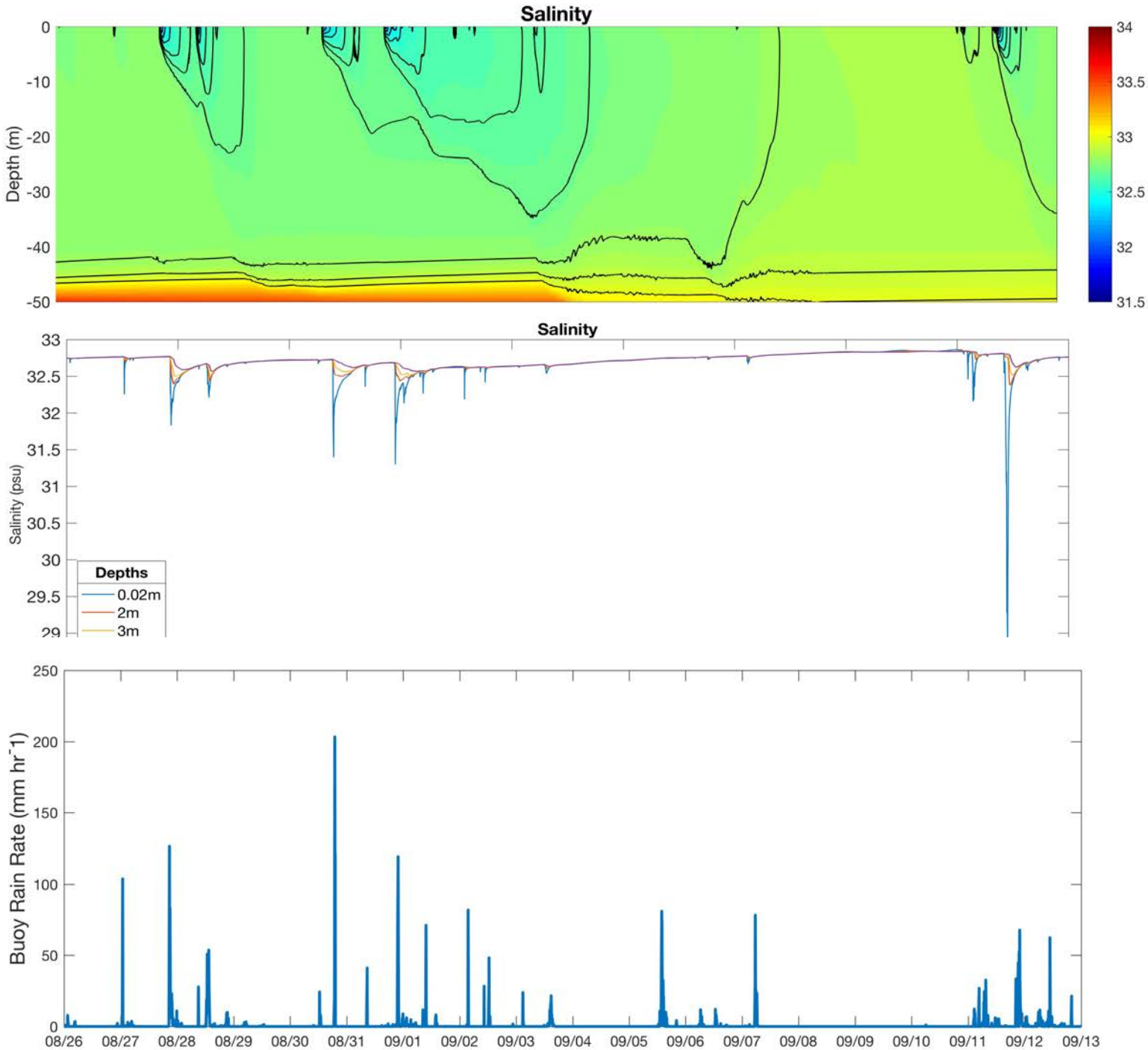
Model simulation

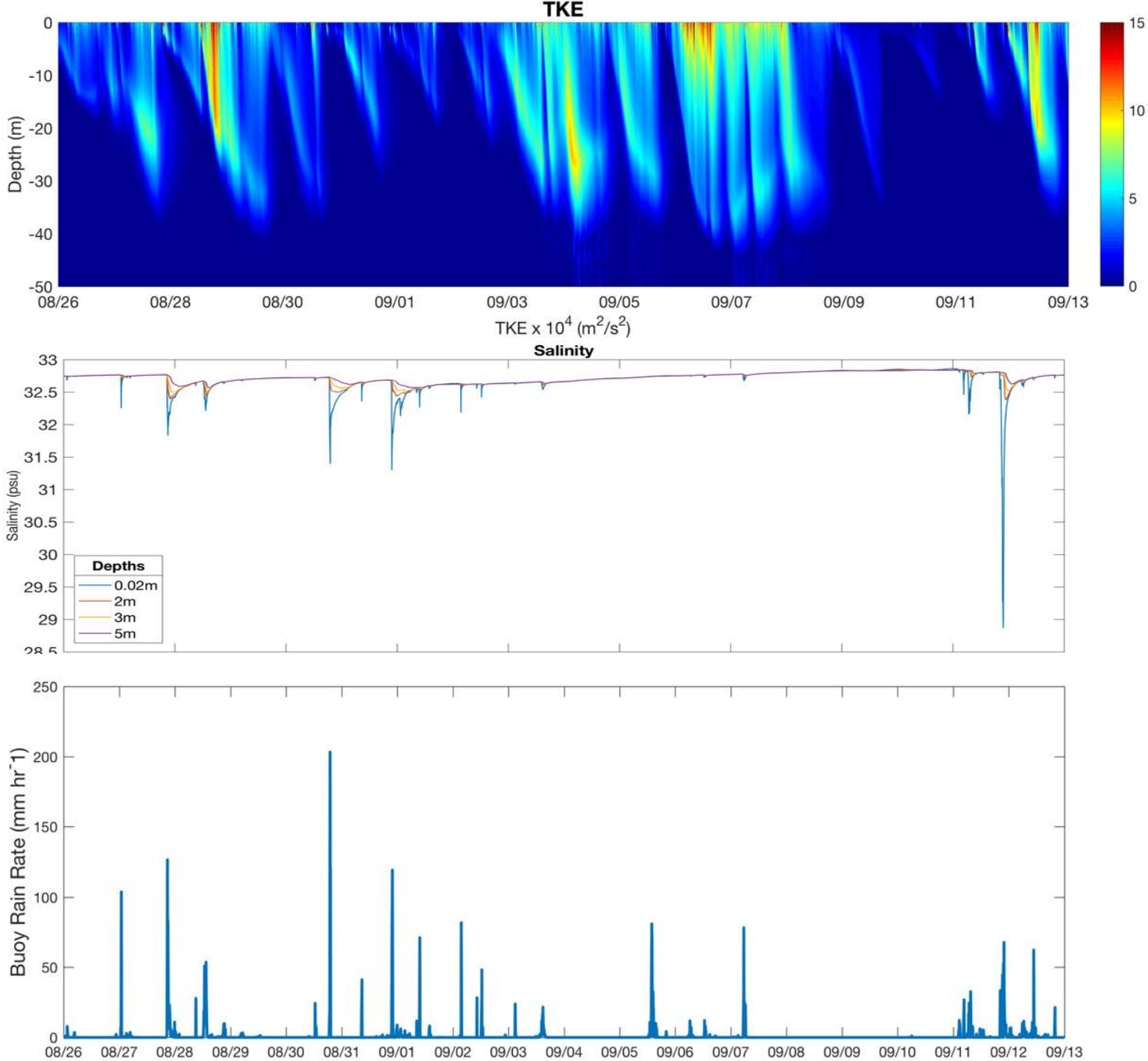




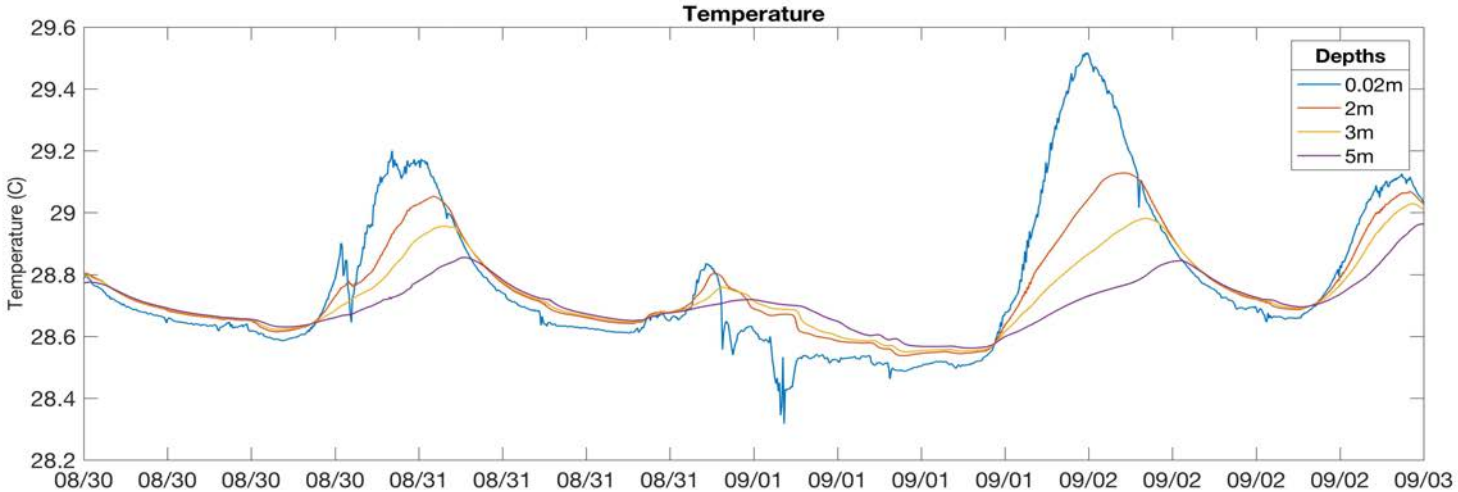
Mixing

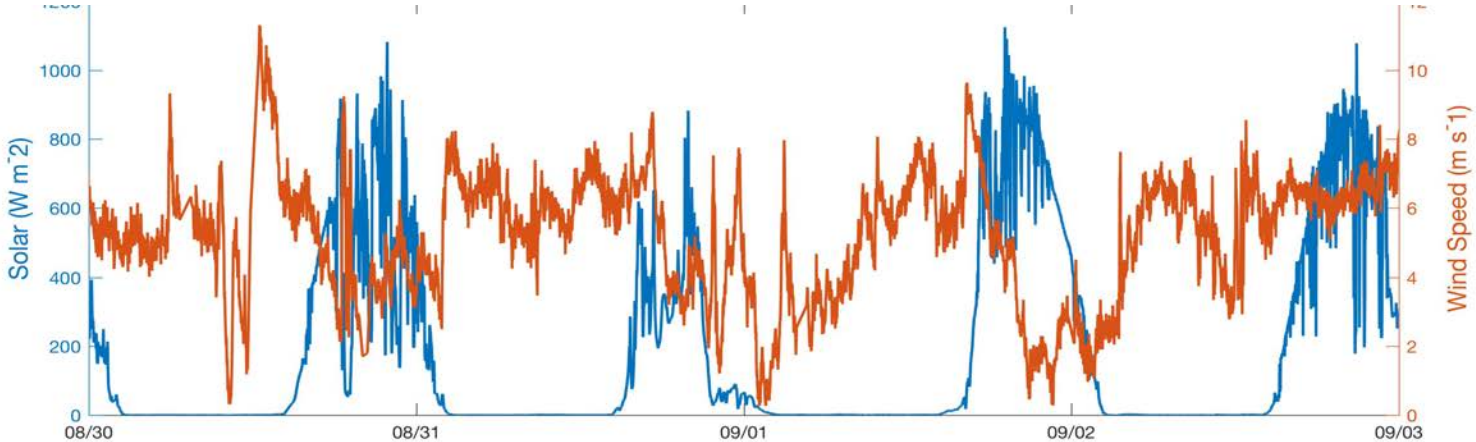

TKE
Depth (m)
0
-10
-20
-30
-40
-50
08/26
08/28
08/30
09/01
09/03
09/05
09/07
09/09
09/11
09/13
TKE x 10^4 (m^2/s^2)
15
10
5
0
Solar (W m^-2)
1200
1000
800
600
400
200
0
08/26
08/27
08/28
08/29
08/30
08/31
09/01
09/02
09/03
09/04
09/05
09/06
09/07
09/08
09/09
09/10
09/11
09/12
09/13
Wind Speed (m s^-1)
14
12
10
8
6
4
2
0

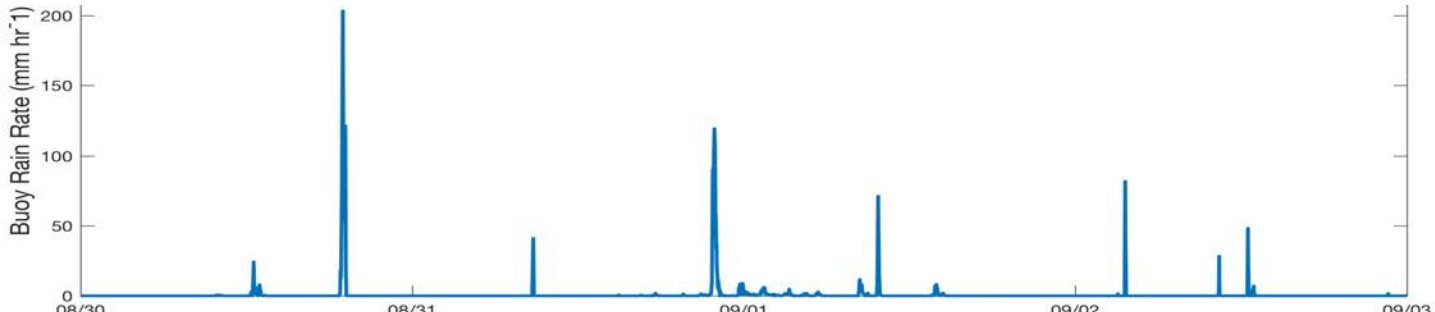

Salinity
Depth (m)
0
-10
-20
-30
-40
-50
34
33.5
33
32.5
32
31.5
Salinity
Salinity (psu)
33
32.5
32
31.5
31
30.5
30
29.5
29
Depths
0.02m
2m
3m
Buoy Rain Rate (mm hr^-1)
250
200
150
100
50
0
08/26
08/27
08/28
08/29
08/30
08/31
09/01
09/02
09/03
09/04
09/05
09/06
09/07
09/08
09/09
09/10
09/11
09/12
09/13


TKE
Depth (m)
0
-10
-20
-30
-40
-50
08/26
08/28
08/30
09/01
09/03
09/05
09/07
09/09
09/11
09/13
TKE x 10^4 (m^2/s^2)
15
10
5
0
Salinity
Salinity (psu)
33
32.5
32
31.5
31
30.5
30
29.5
29
Depths
0.02m
2m
3m
5m
Buoy Rain Rate (mm hr^-1)
250
200
150
100
50
0
08/26
08/27
08/28
08/29
08/30
08/31
09/01
09/02
09/03
09/04
09/05
09/06
09/07
09/08
09/09
09/10
09/11
09/12
09/13

August 30 – September 3

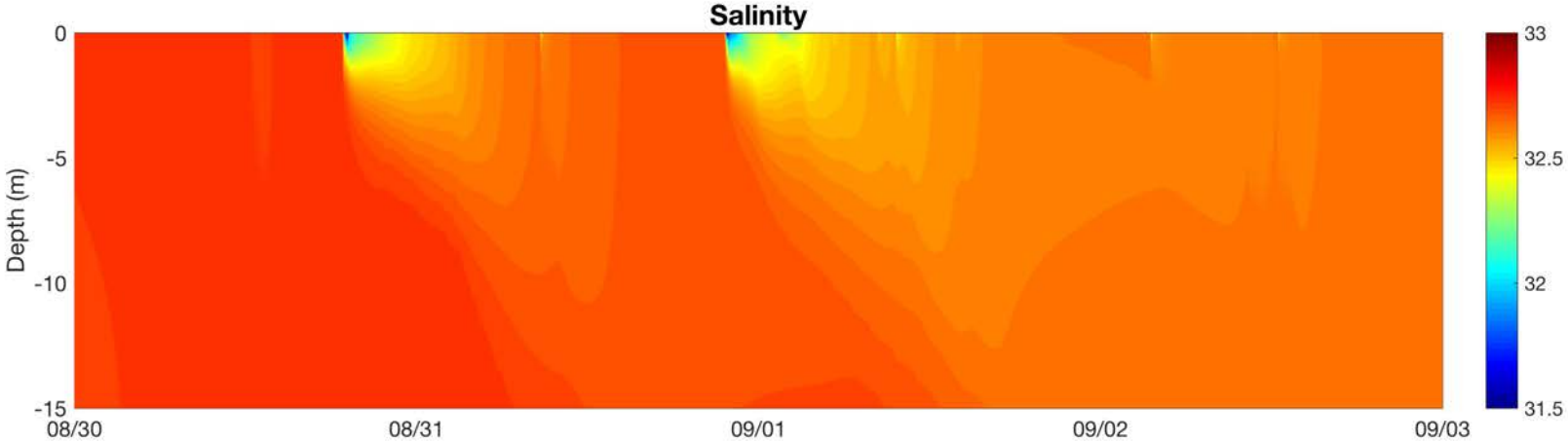


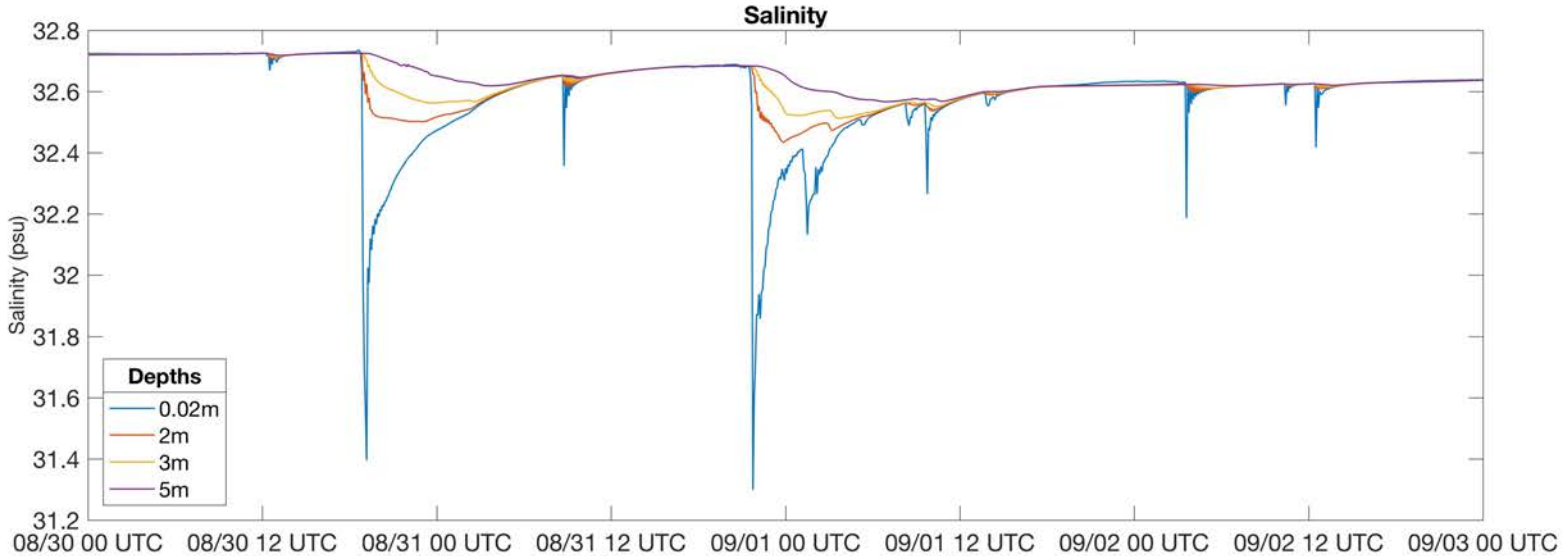




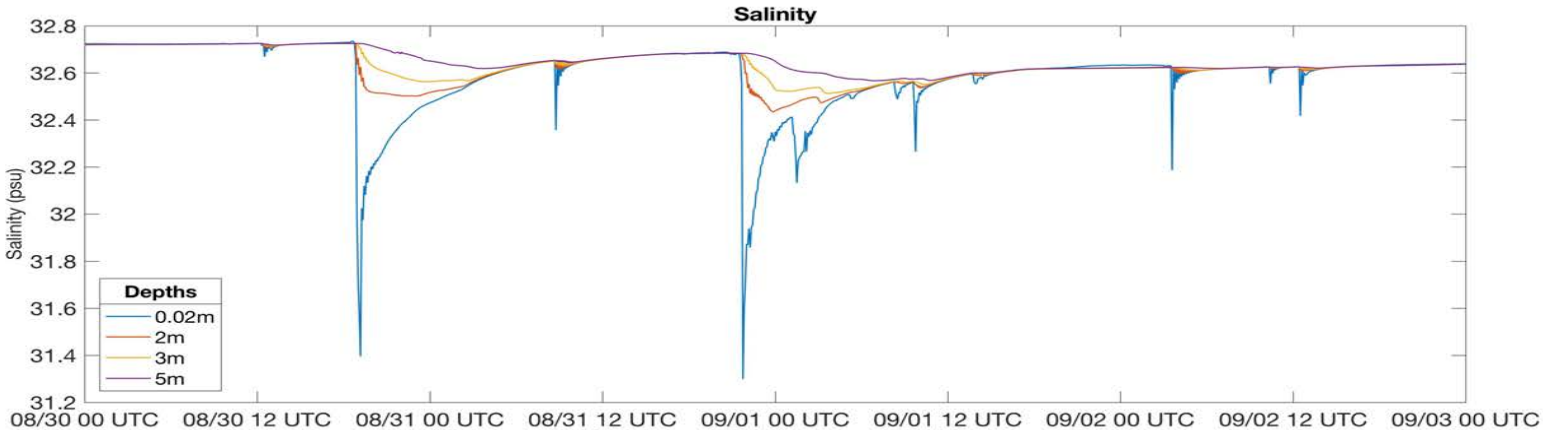
August 30 event

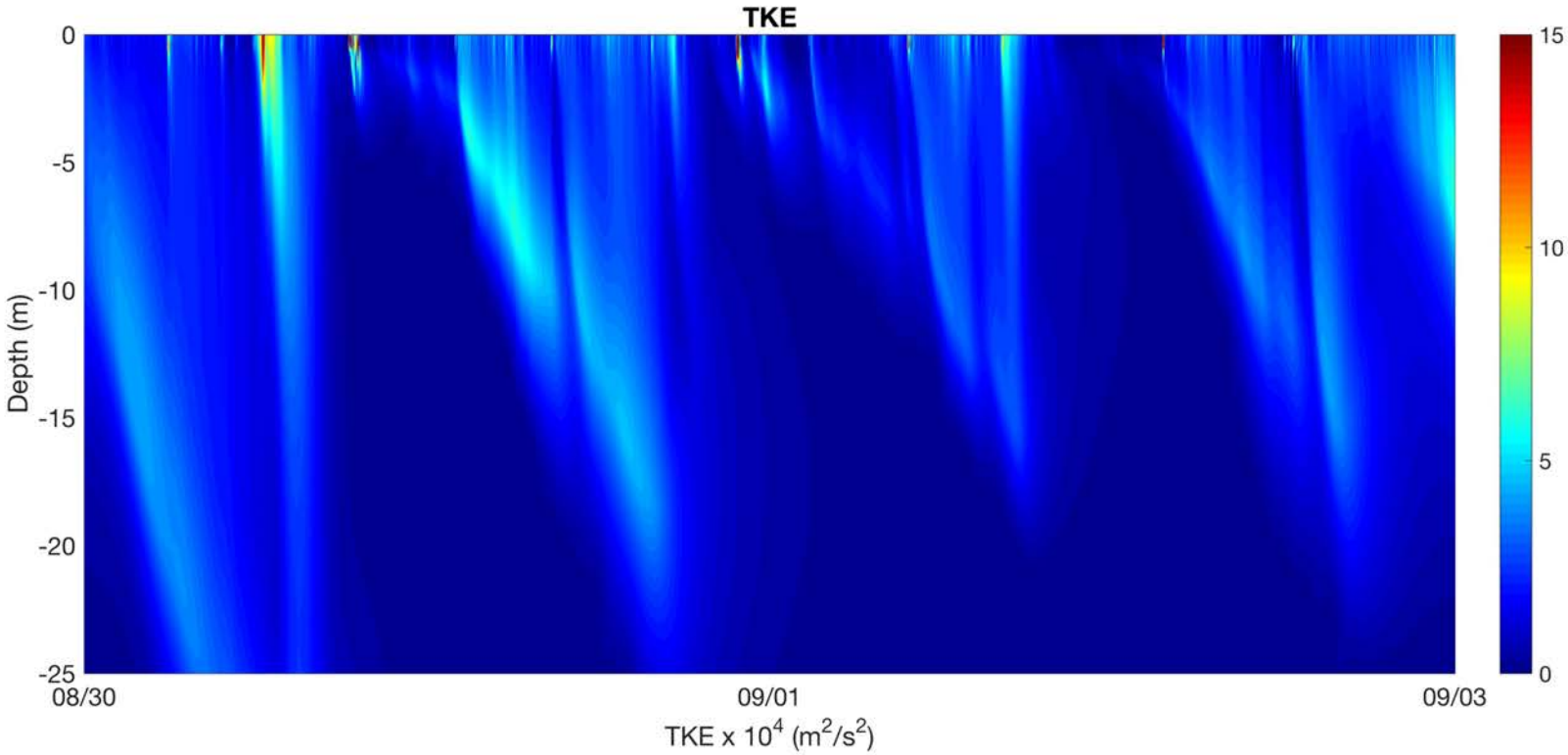
August 30 – September 3



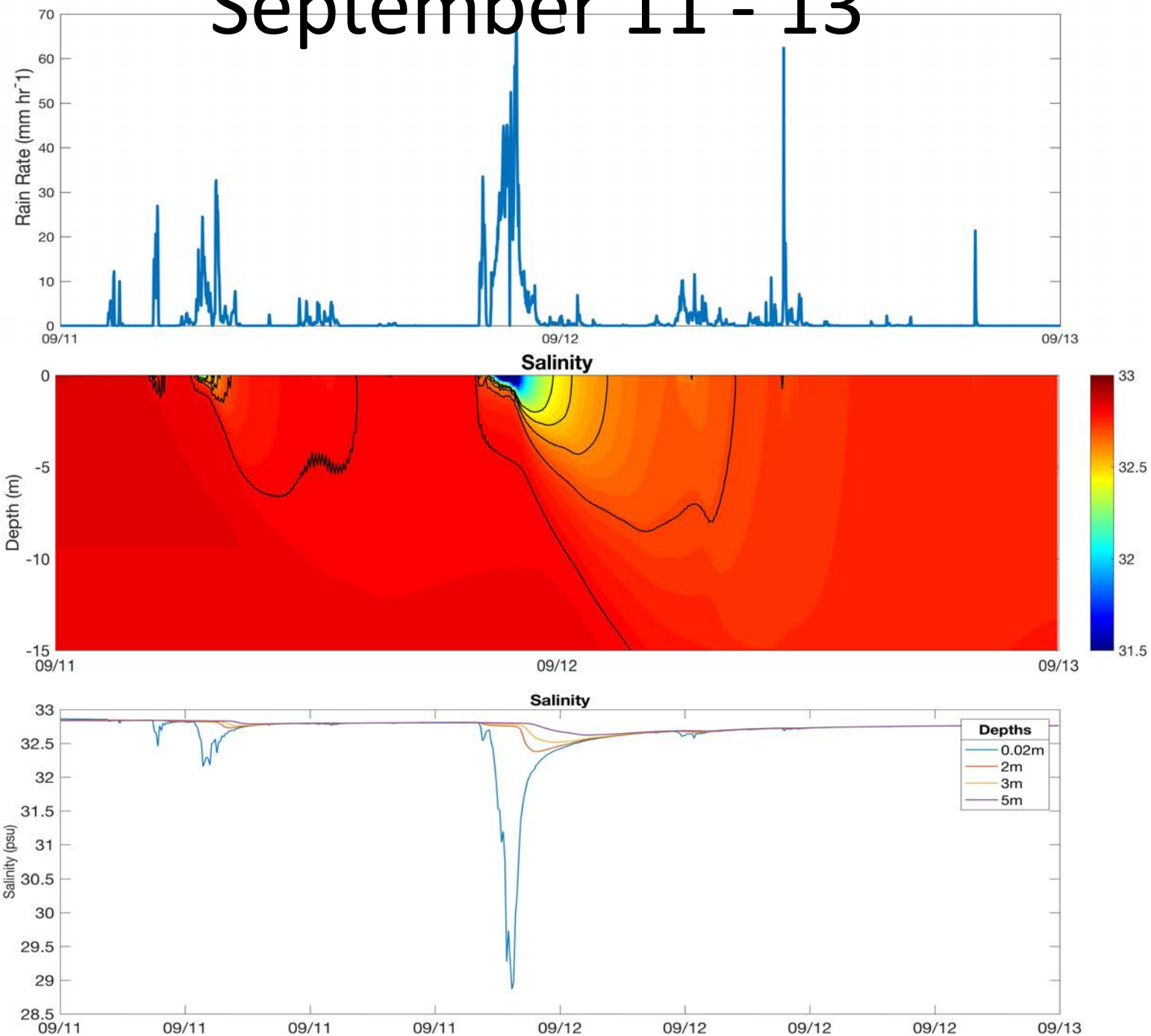


August 30 – September 3



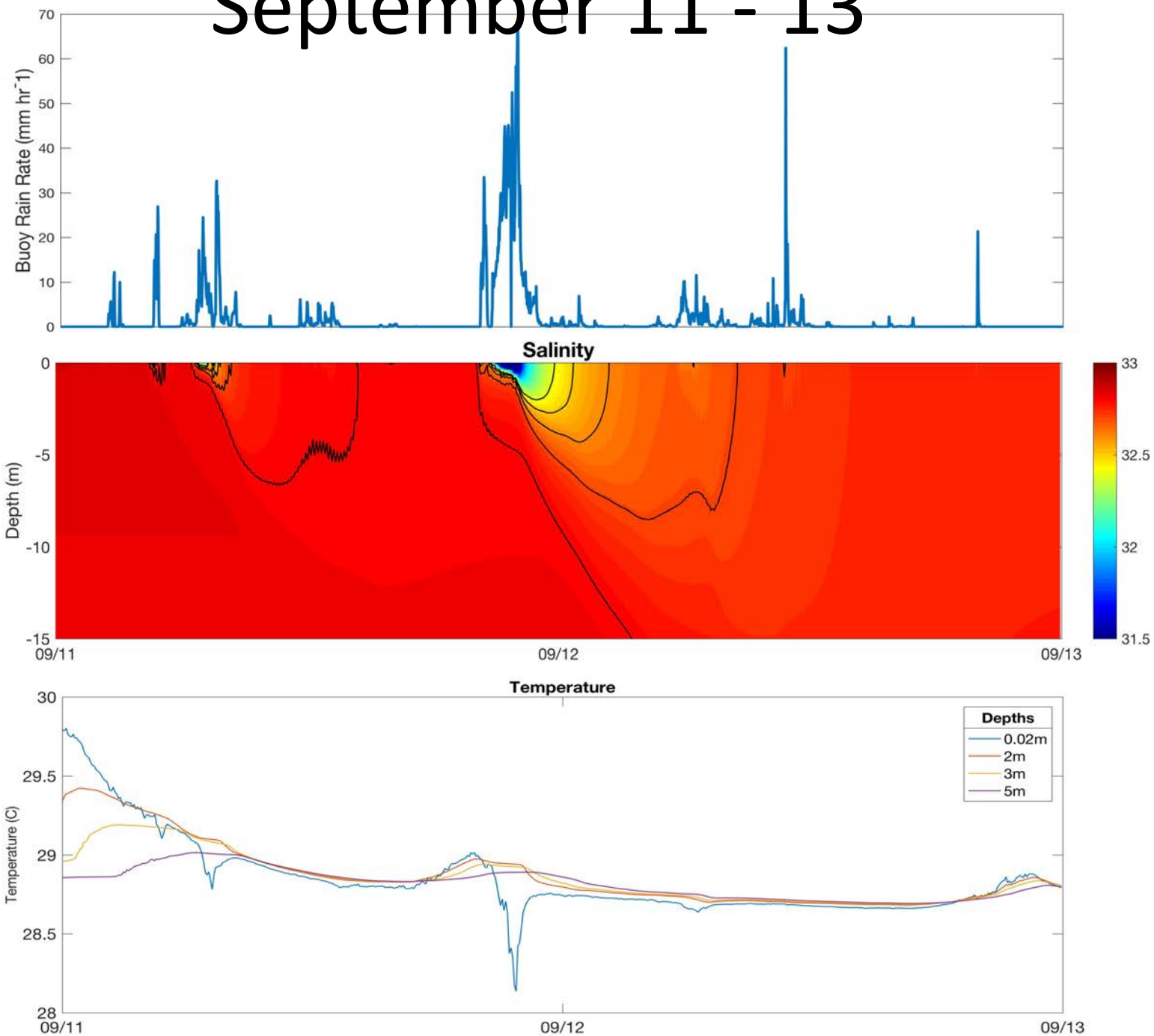


September 11 - 13

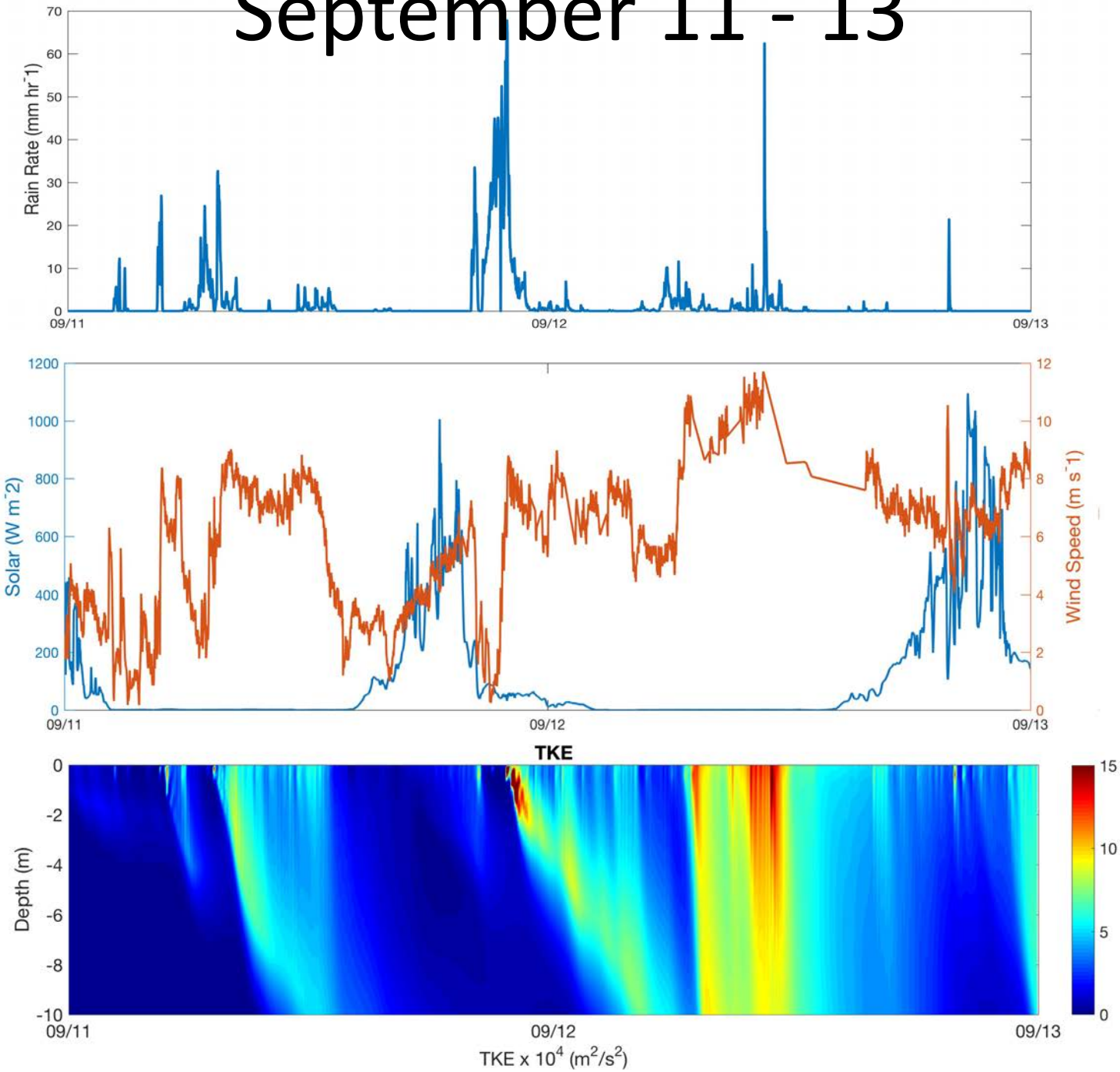


September 11 event

September 11 - 13



September 11 - 13



Conclusions

Conclusions

- Internal waves from deep ocean can tunnel through the remnant mixed layer and cause enhanced shear across DWL. Observations are consistent with this mechanism.
- Presumably this is conceivable for a freshwater-induced stably stratified surface layer.
- Traditional 1-D mixing mechanisms predict cessation of mixing due to stabilizing impact from warming or rainfall.
- Rainfall may also create mechanism for stabilizing remnant mixed layer enhancing IW formation.
- Colder rainfall disrupts diurnal warming, causing increased turbulence
- As with diurnal warming, rainfall effects are diminished and delayed with depth

Questions