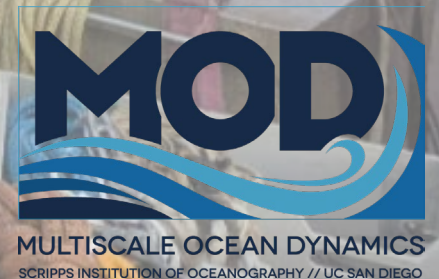
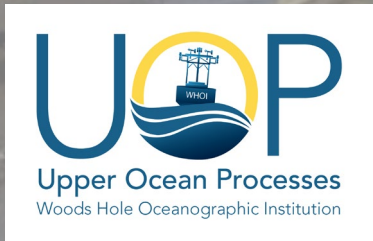


# Observed Air–Sea Interaction During Atmospheric River Events in the Central Pacific

Tom Farrar and Drew Lucas



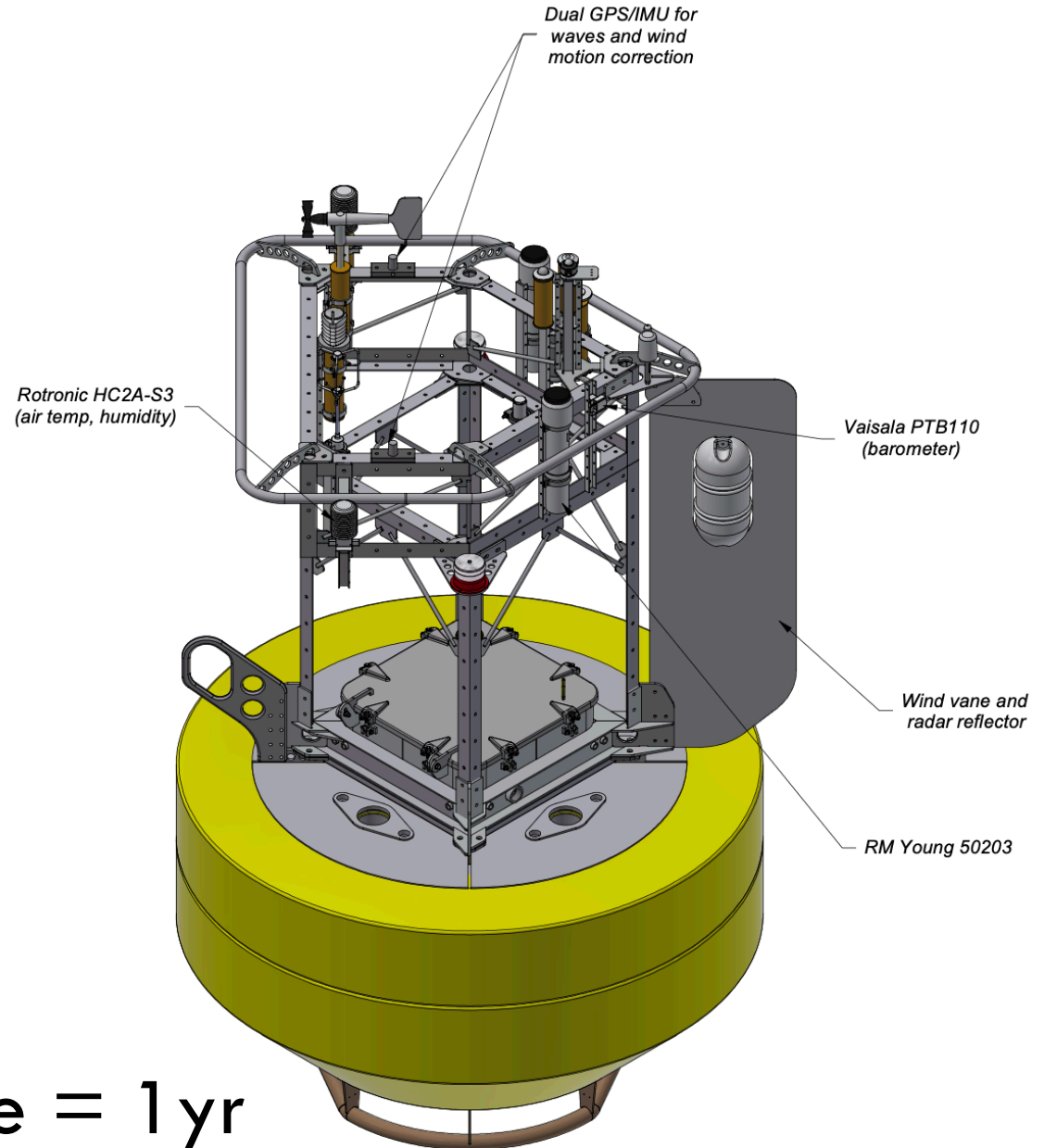
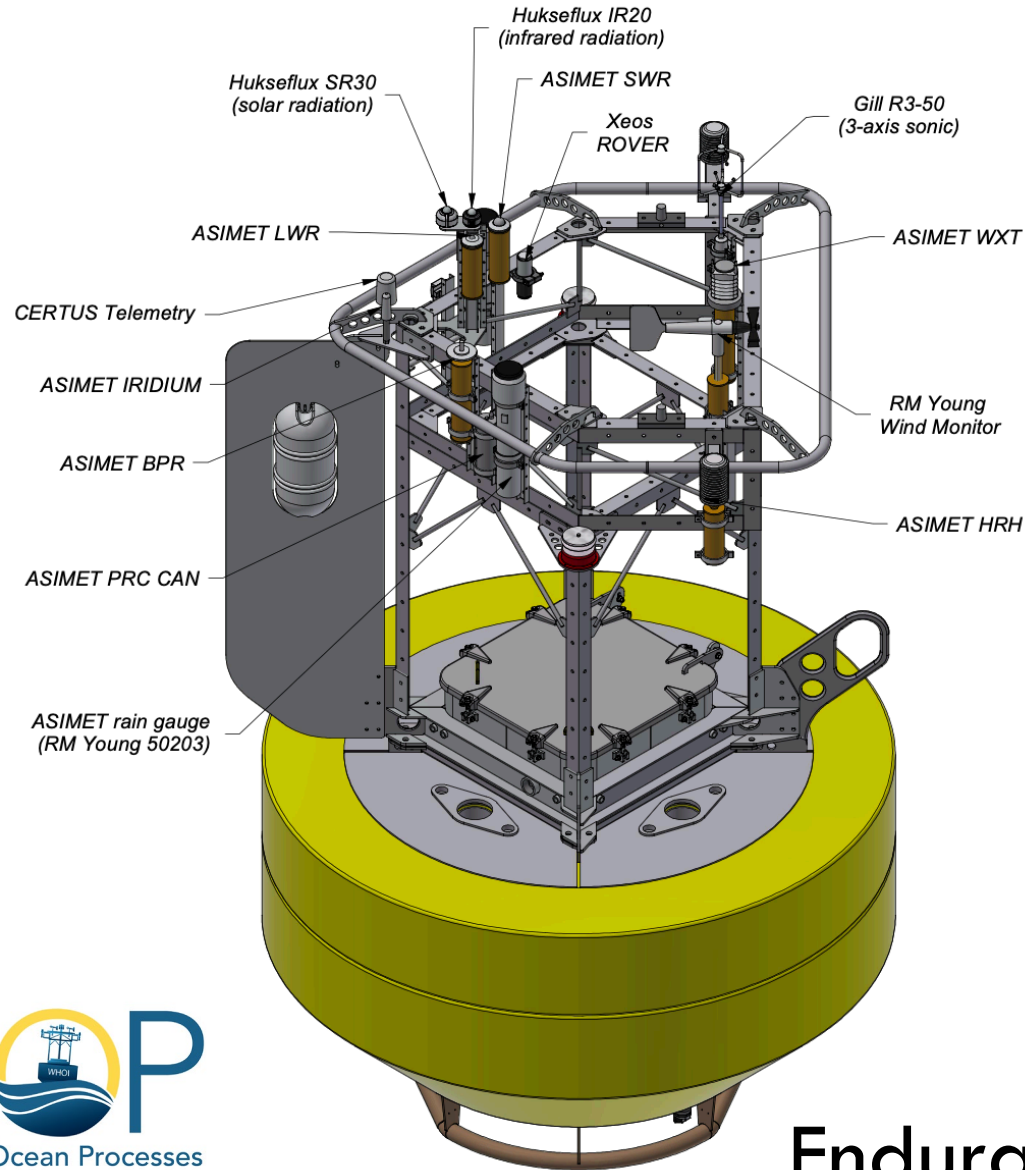
# Project goal is to study air-sea interaction in atmospheric rivers

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Specifically, we're interested in:

- Air-sea fluxes of heat, momentum and water in atmospheric rivers
- Physical processes affecting SST and air-sea fluxes (ocean waves, currents, mixing; high-frequency atmospheric processes)

# SAFARI buoy instrumentation

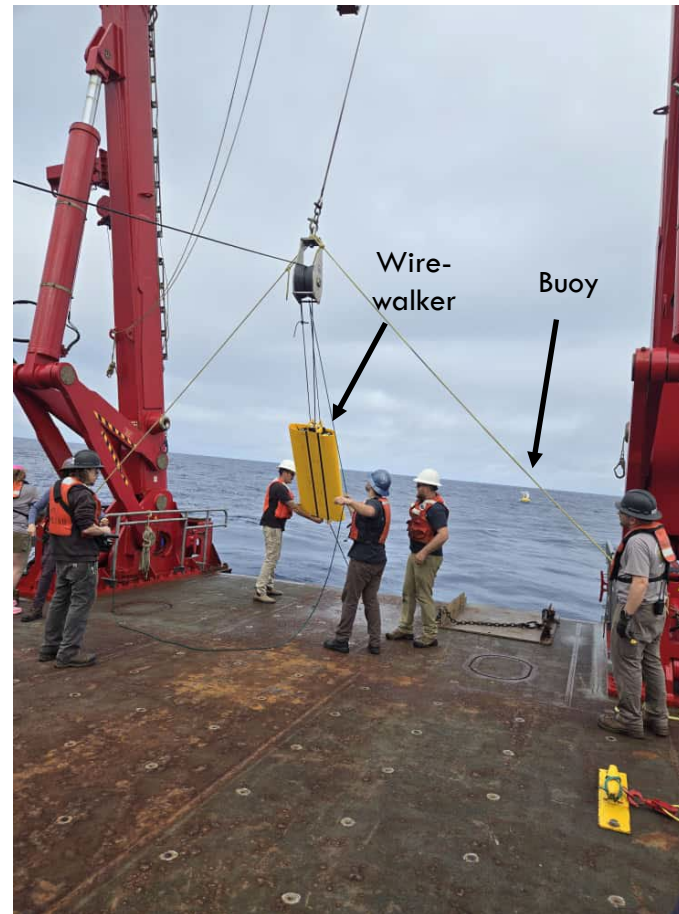
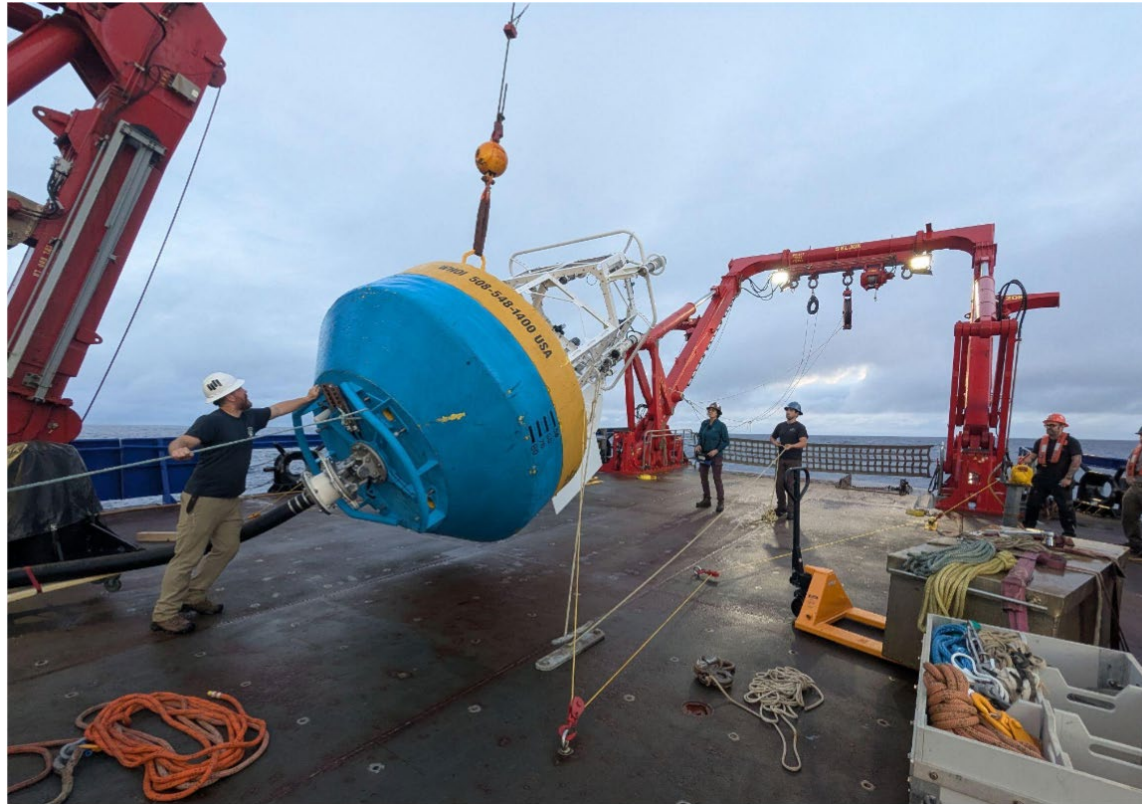


Endurance = 1 yr

# Mooring measures surface met/flux, waves, upper-ocean properties



Nov. 2025 deployment

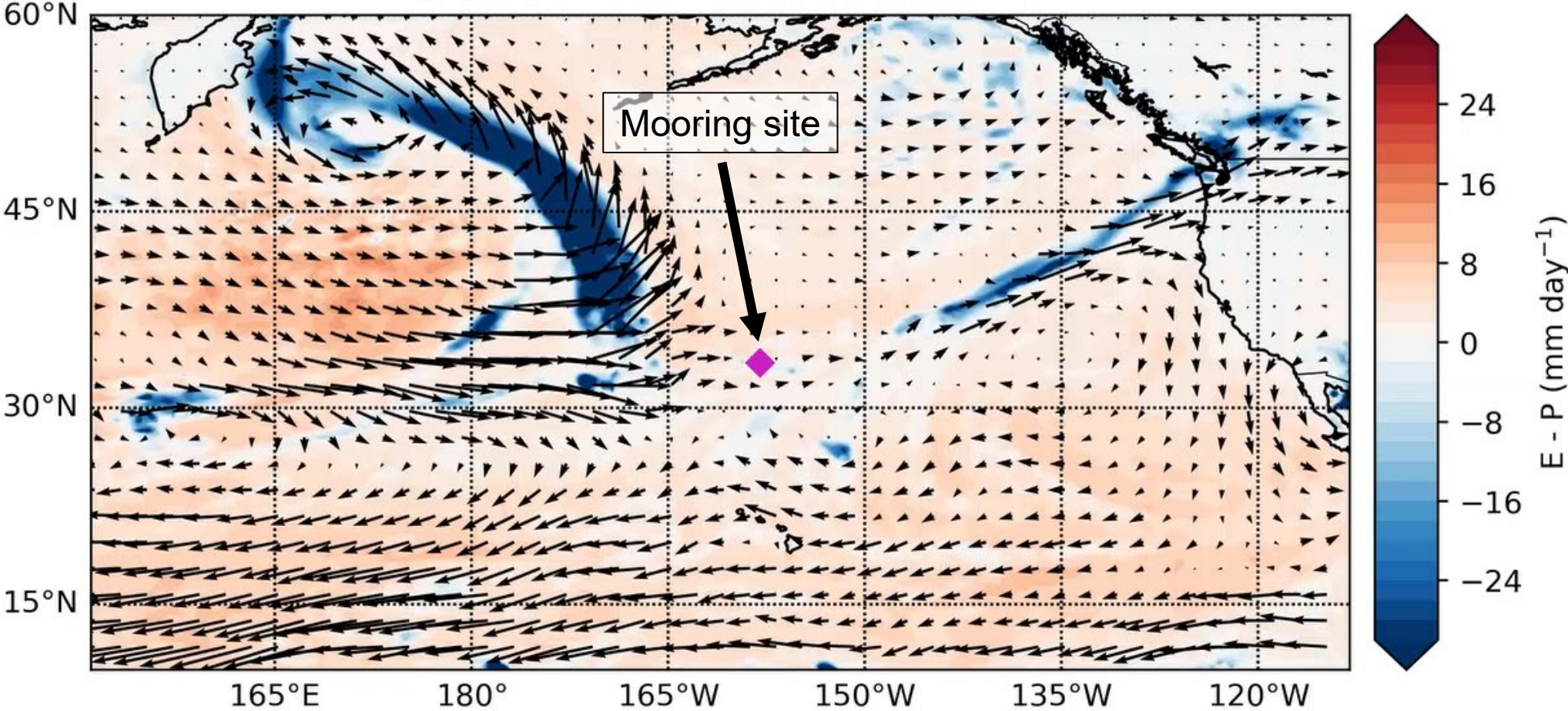


Wirewalker carries instruments for T, S, currents and uses wave energy to profile upper 300m every ~20 min

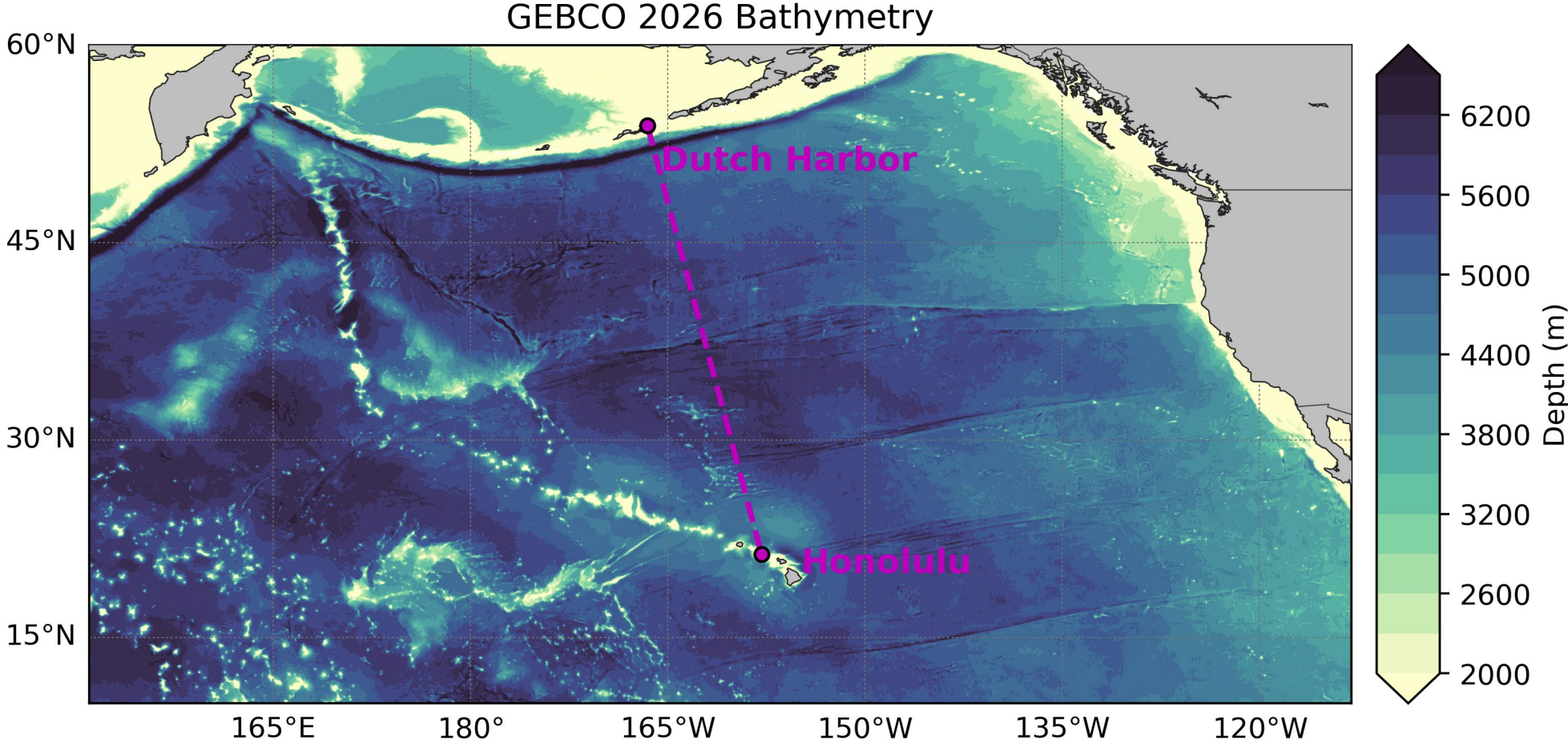
# Project goal is to study air-sea interaction in atmospheric rivers

ERA5 evaporation-minus-precipitation (colors) with IVT (vectors)  
(vectors)

2025-11-23T04:00:00.000000000

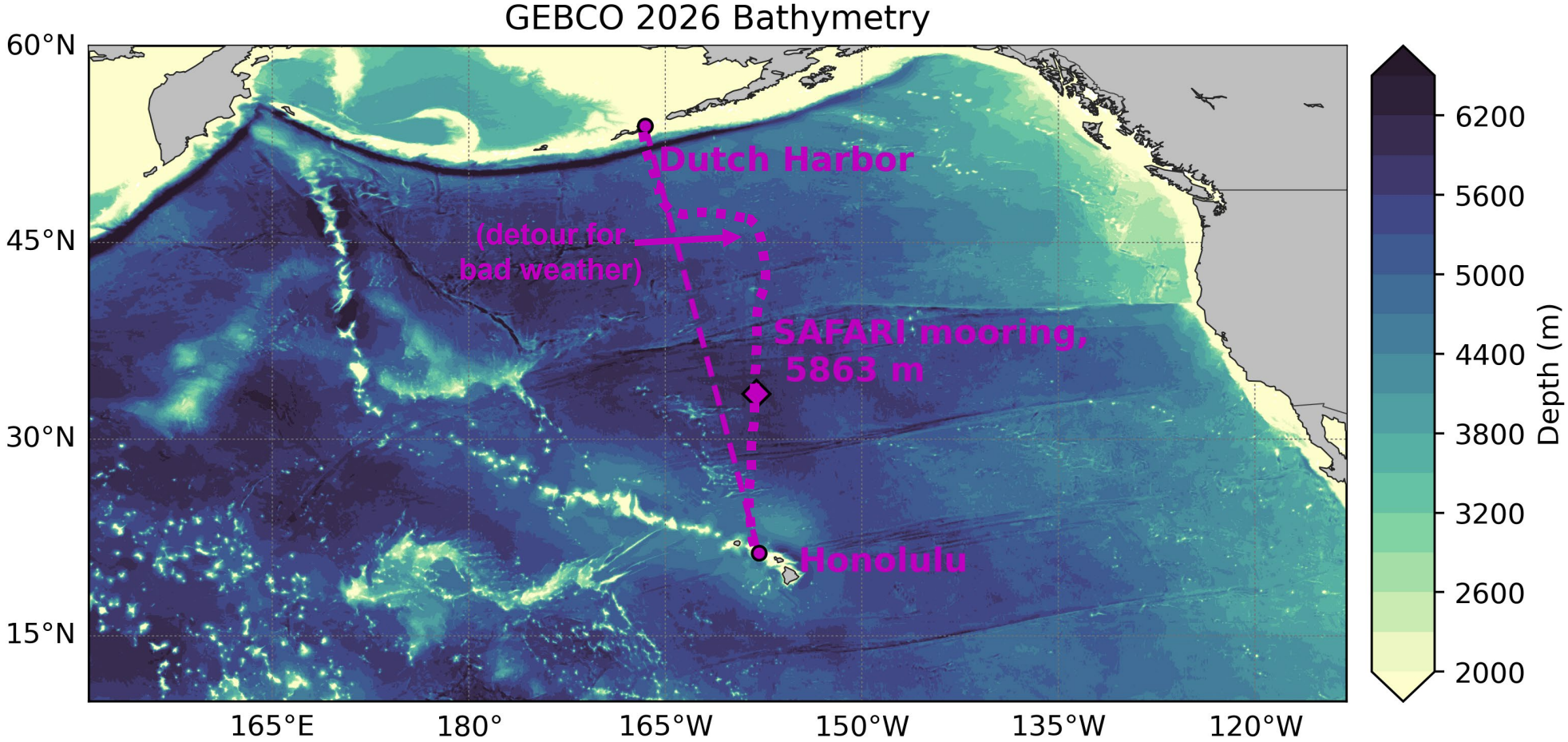


# Site selection in the central North Pacific



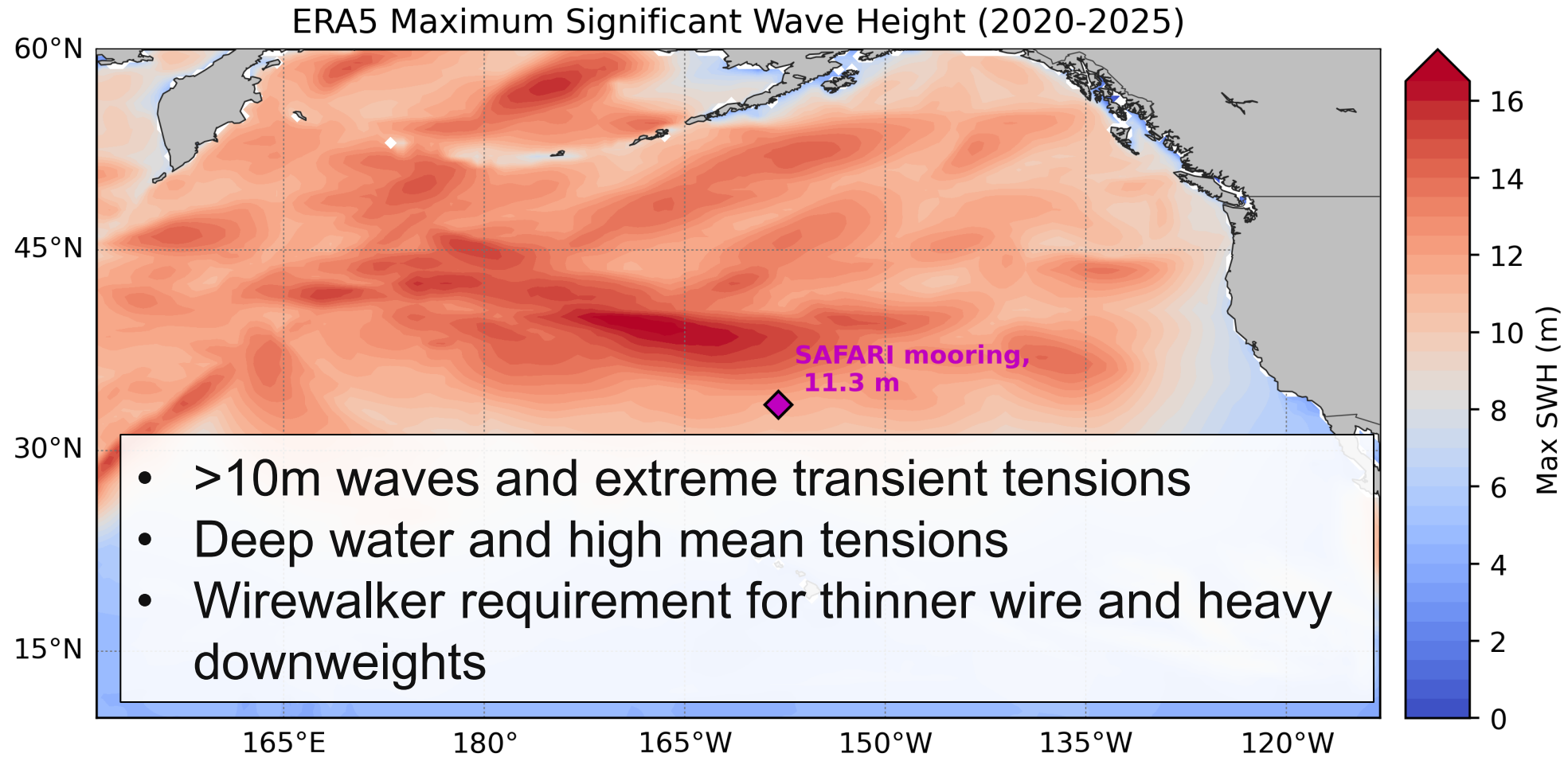
Deployment on transit leg of *RV Sikuliaq* from Dutch Harbor to Honolulu constrained the feasible daytime deployment site.

# Site selection in the central North Pacific



The selected site samples central Pacific ARs and high-region evaporation north of of Hawaii.

# Mooring design challenges



This is a challenging place for a surface mooring, due to the depth (5900m) and >10m waves.

# Mooring Design



Mooring Length = 7,025.314 m

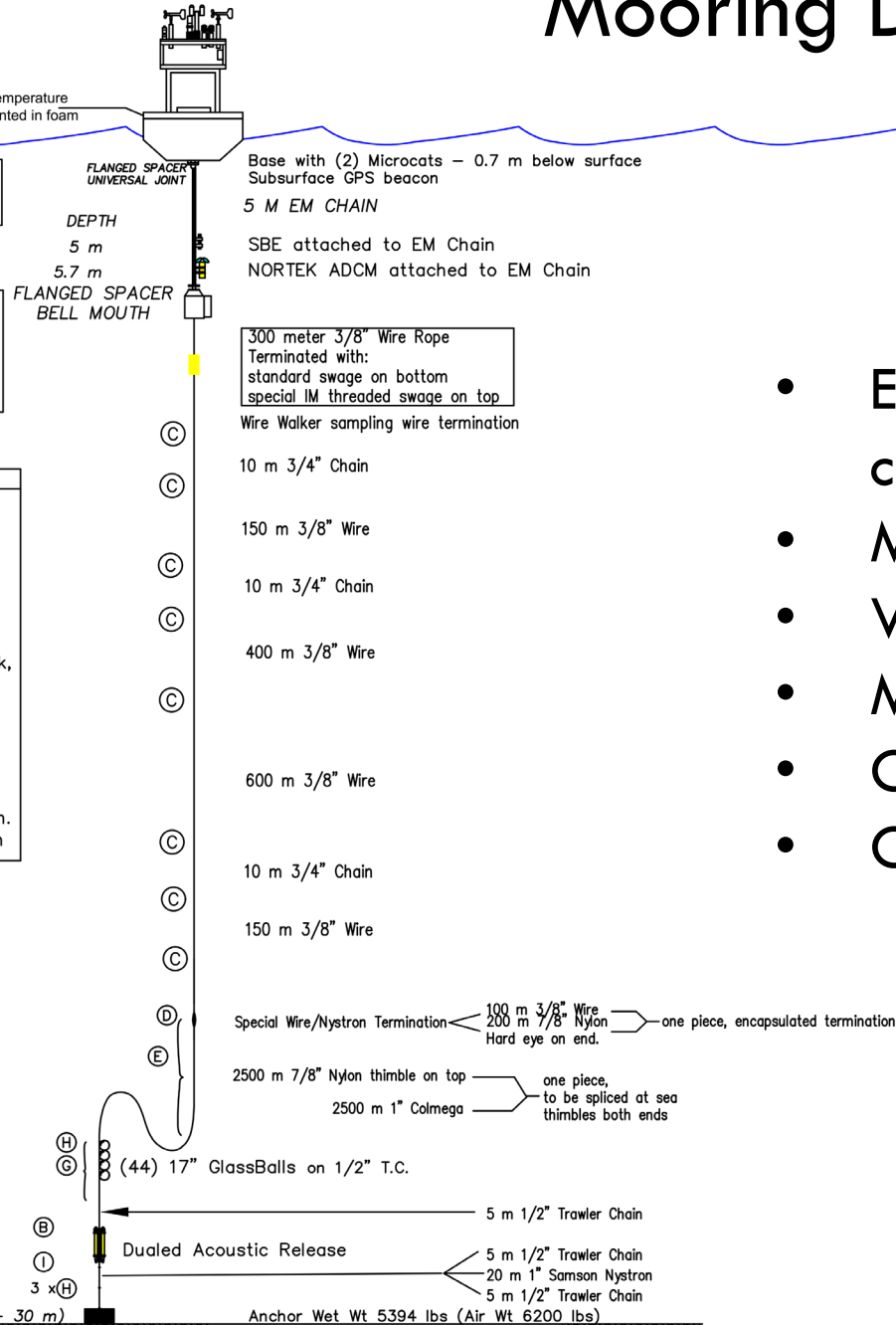
(4) SBE56 temperature loggers mounted in foam

5 meter compliant section with universal and 8 conductors on coil cord for telemetry

The top of the EM chain is 1.99 m from the buoy deck. Assuming a 0.80 m waterline, the 2.5 m SBE should be mounted 1.31 m from the top of the EM chain. The Nortek head should be mounted 2.01 m from the top of the EM chain.

HARDWARE DESIGNATION	
(B)	3/4" Chain Shackle, 7/8" EndLink, 5/8" Chain Shackle
(C)	3/4" Chain Shackle, 7/8" EndLink, 3/4" Chain Shackle
(D)	3/4" Chain Shackle, 7/8" EndLink, 3/4" Anchor Shackle
(E)	3/4" Anchor Shackle, 7/8" EndLink, 3/4" Anchor Shackle
(G)	5/8" Chain Shackle, 7/8" EndLink, 5/8" Chain Shackle
(H)	5/8" Chain Shackle, 7/8" EndLink, 7/8" Anchor Shackle
(I)	1-1/4" Master Link, (1) 5/8" Ch Sh. (1) 7/8" End Link, (1) 7/8" Anc Sh

HARDWARE DESIGNATION	
(B)	QTY: 1
(C)	QTY: 8
(D)	QTY: 1
(E)	QTY: 1
(G)	QTY: 11
(H)	QTY: 4
(I)	QTY: 1



Water Depth = 5880 m (+ - 30 m)

- Extensive mooring simulations of extreme conditions
- Mooring location (nominal) ~ 33.4N 158W
- Water depth ~5,900 m (3.5 miles)
- Mooring length ~7,000 m (4.4 miles)
- Ocean profiling range = 5 – 300 m depth
- Ocean profiling repeat rate ~ 75 per day

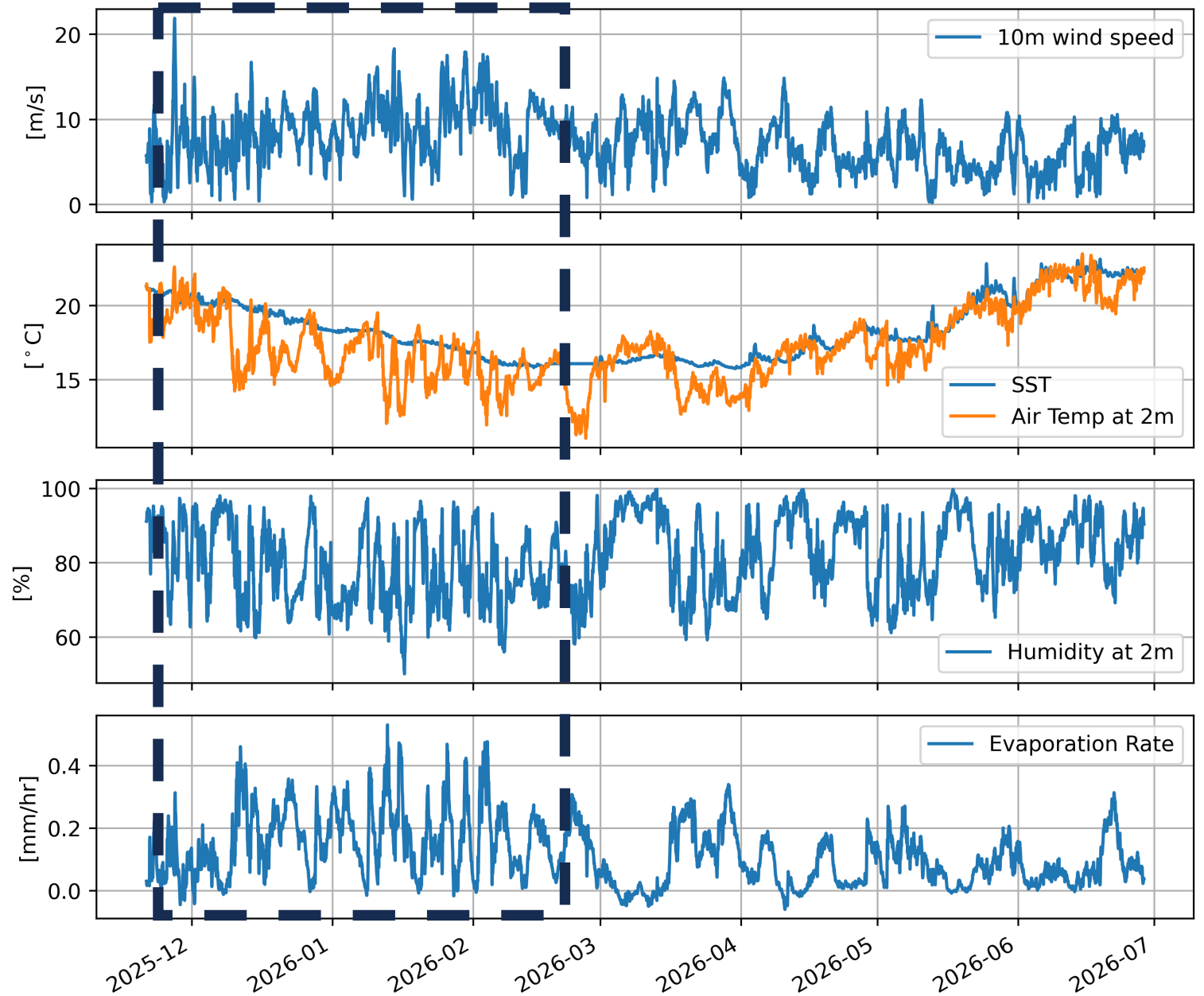
# Broad view of the AR season

- Strong winds, humidity, and air temperature variations during the the AR season
- Multi-day periods with  $\sim 0.5$  mm/hr evaporation (or 5 cm over over 4 days)

Surface heat/water/momentum fluxes estimated using “COARE” bulk formulas (Fairall et al., 1996)

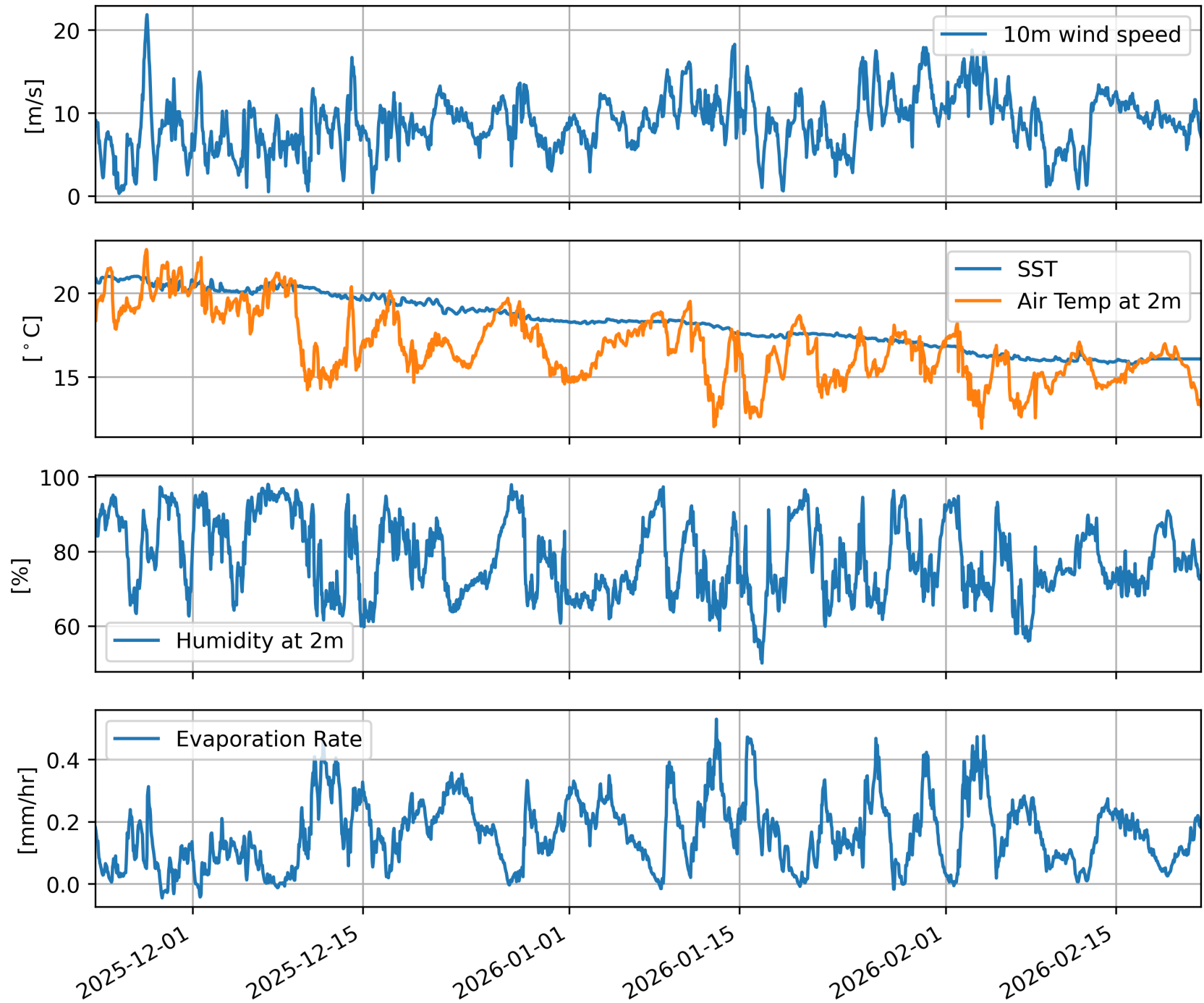
Latent heat flux  $Q_E \cong -\rho_a L_v C_E U \Delta q$

Latent heat of vaporization  $L_v$   
 Transfer coefficient  $C_E$   
 Wind speed  $U$   
 Air-sea difference in spec. humidity  $\Delta q$



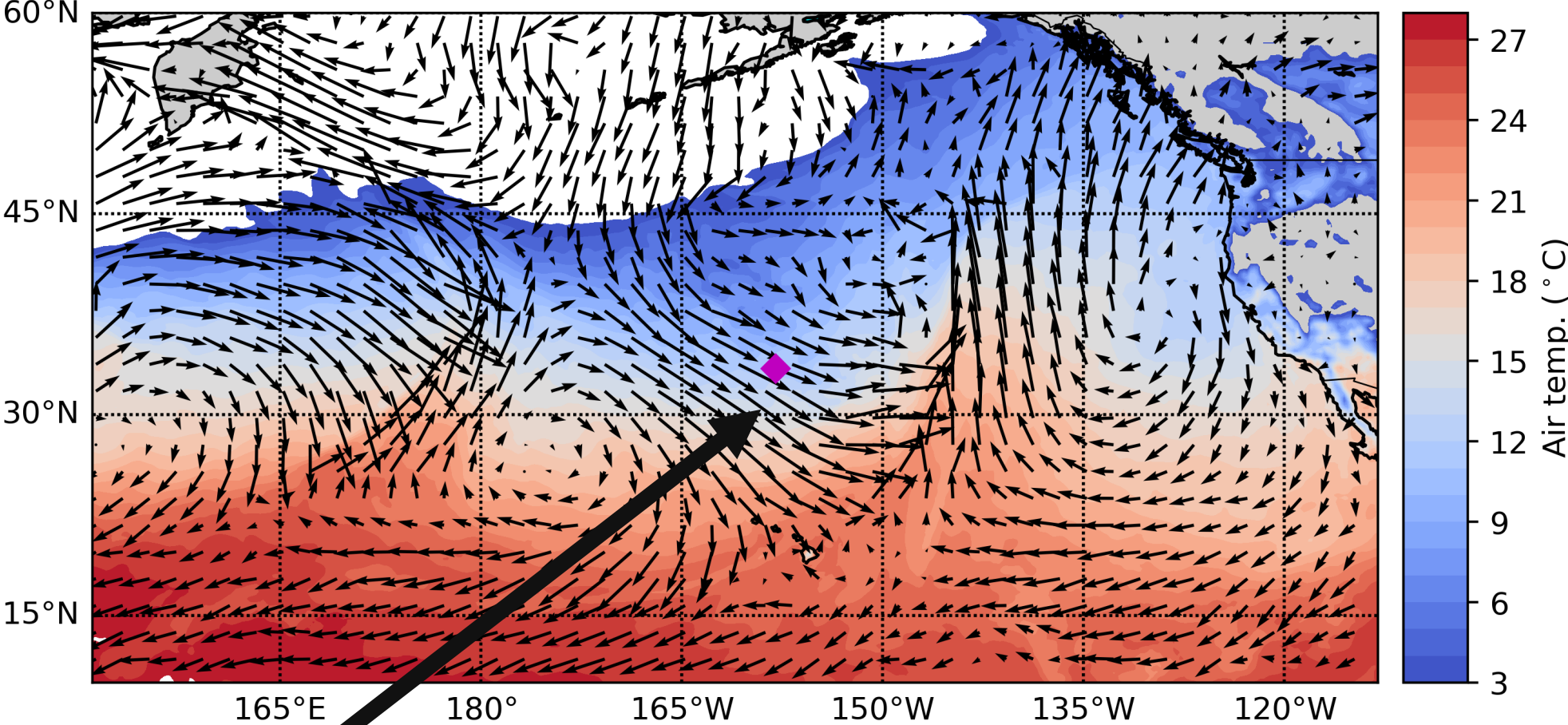
# Zoom on AR-season

Cold, dry air events, strong winds, and evaporation all occur, but not necessarily at the same time



# ERA5 air temperature and surface winds

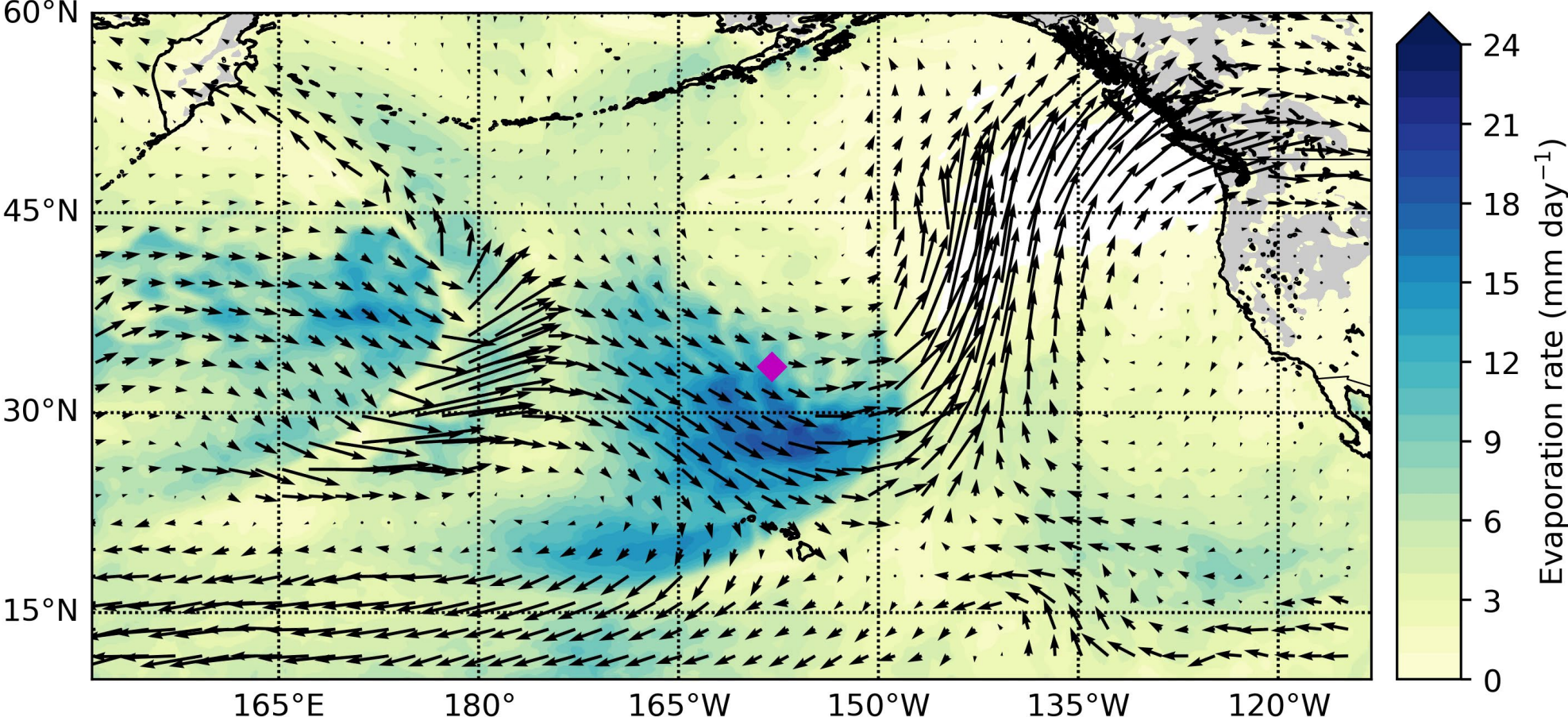
Surface air temperature and surface winds  
2026-01-13T02:00:00.000000000



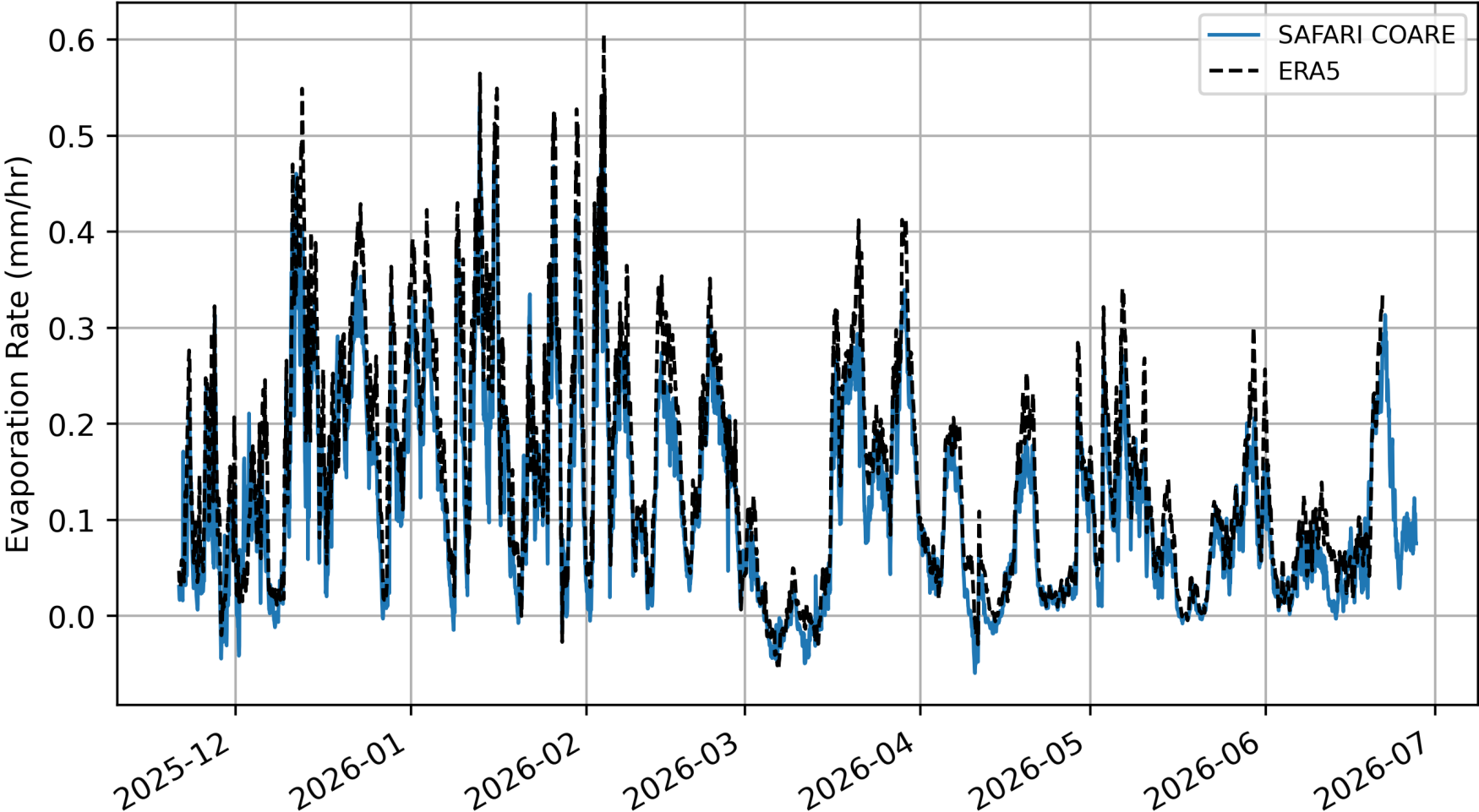
Cold surface air  
behind cold front

# ERA5 evaporation during AR events

Surface evaporation and IVT vectors  
2026-01-13T02:00:00.000000000



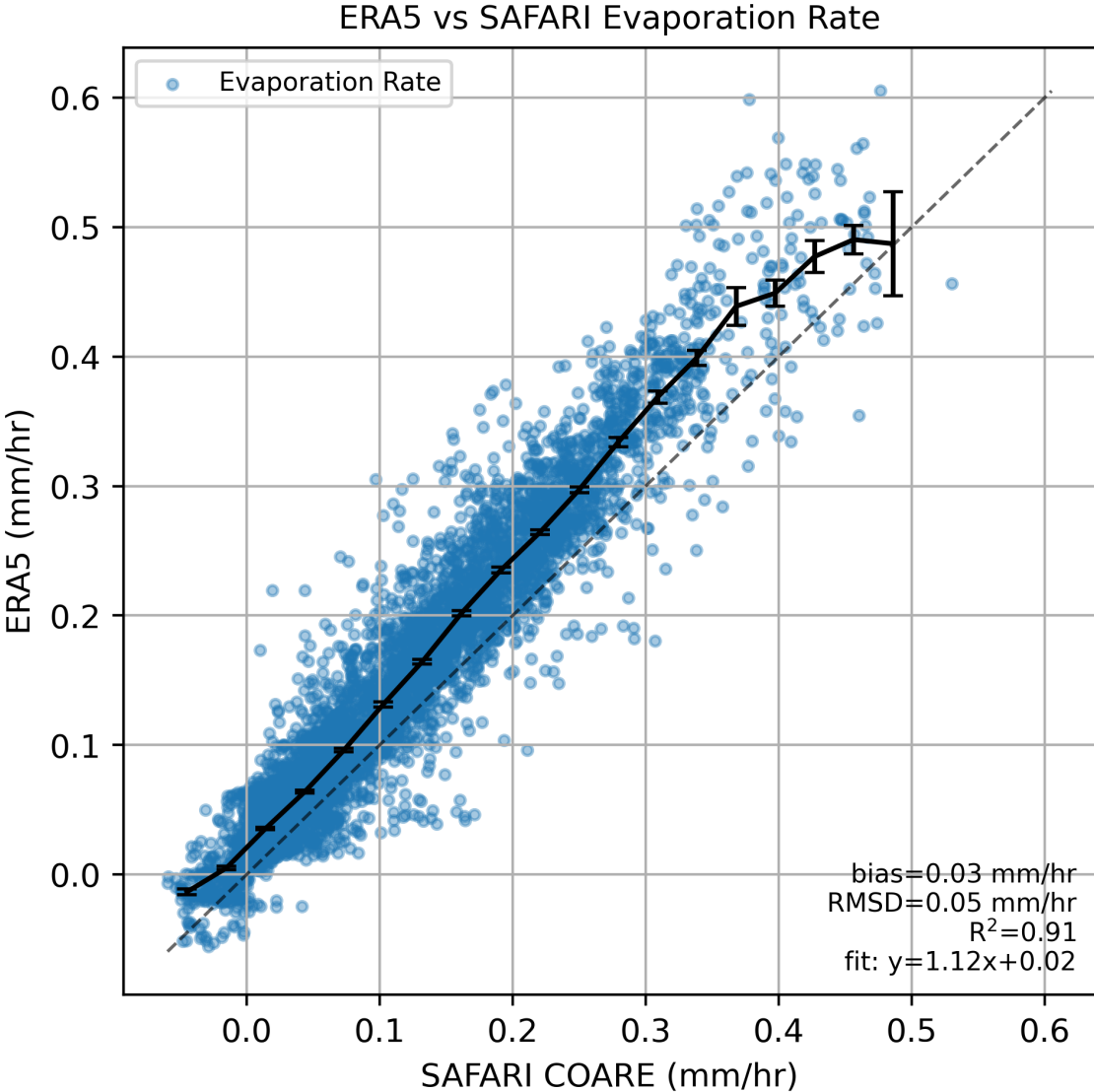
# ERA5-buoy comparison: evaporation time series



ERA5 and buoy-derived evaporation agree in timing but differ in amplitude during some events.

# ERA5-buoy comparison: evaporation scatter

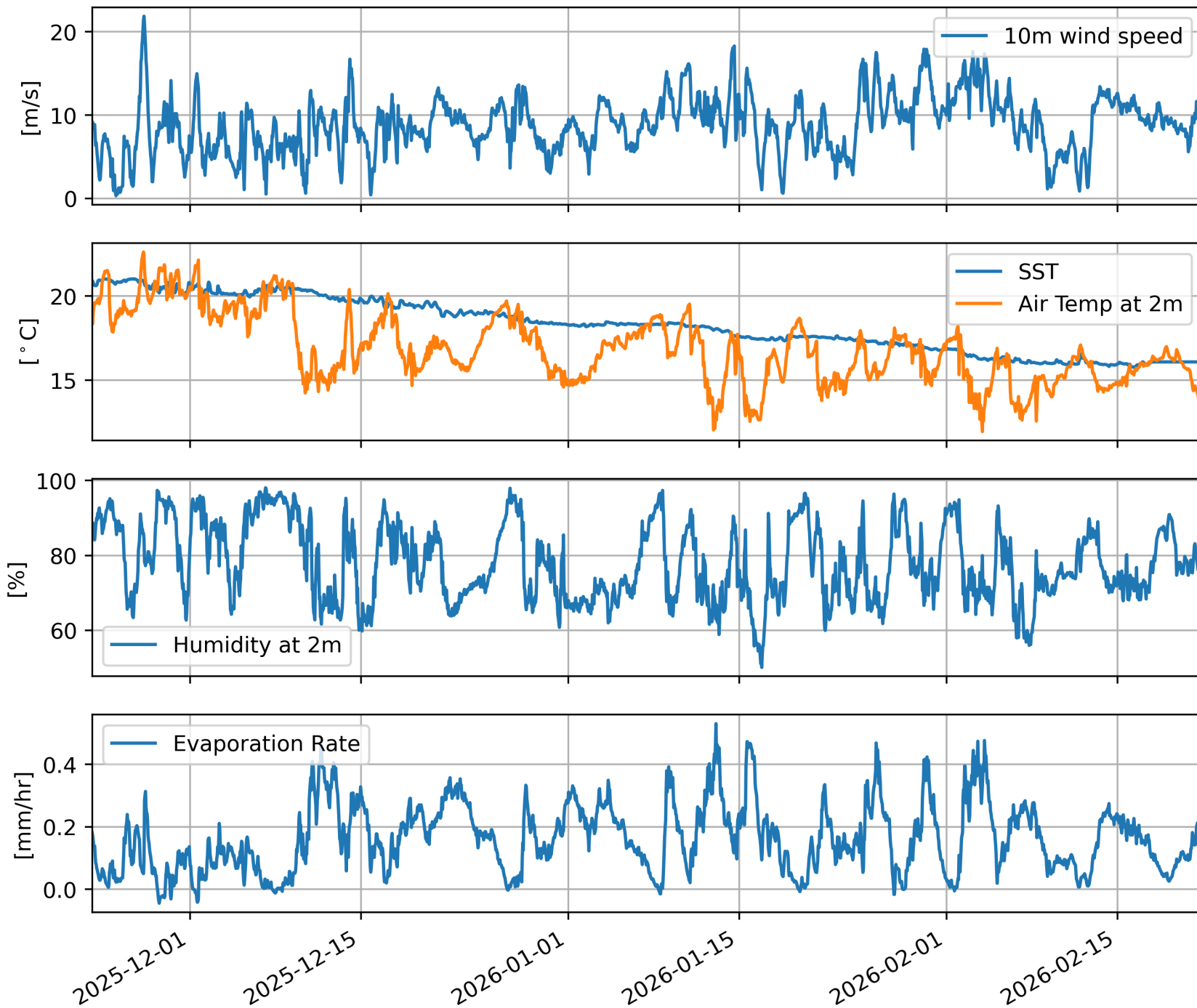
- ERA5 relative humidity is drier than observed
- ERA5 evaporation is high relative to the buoy estimate
- Difference is about 15%



## Zoom on AR-season

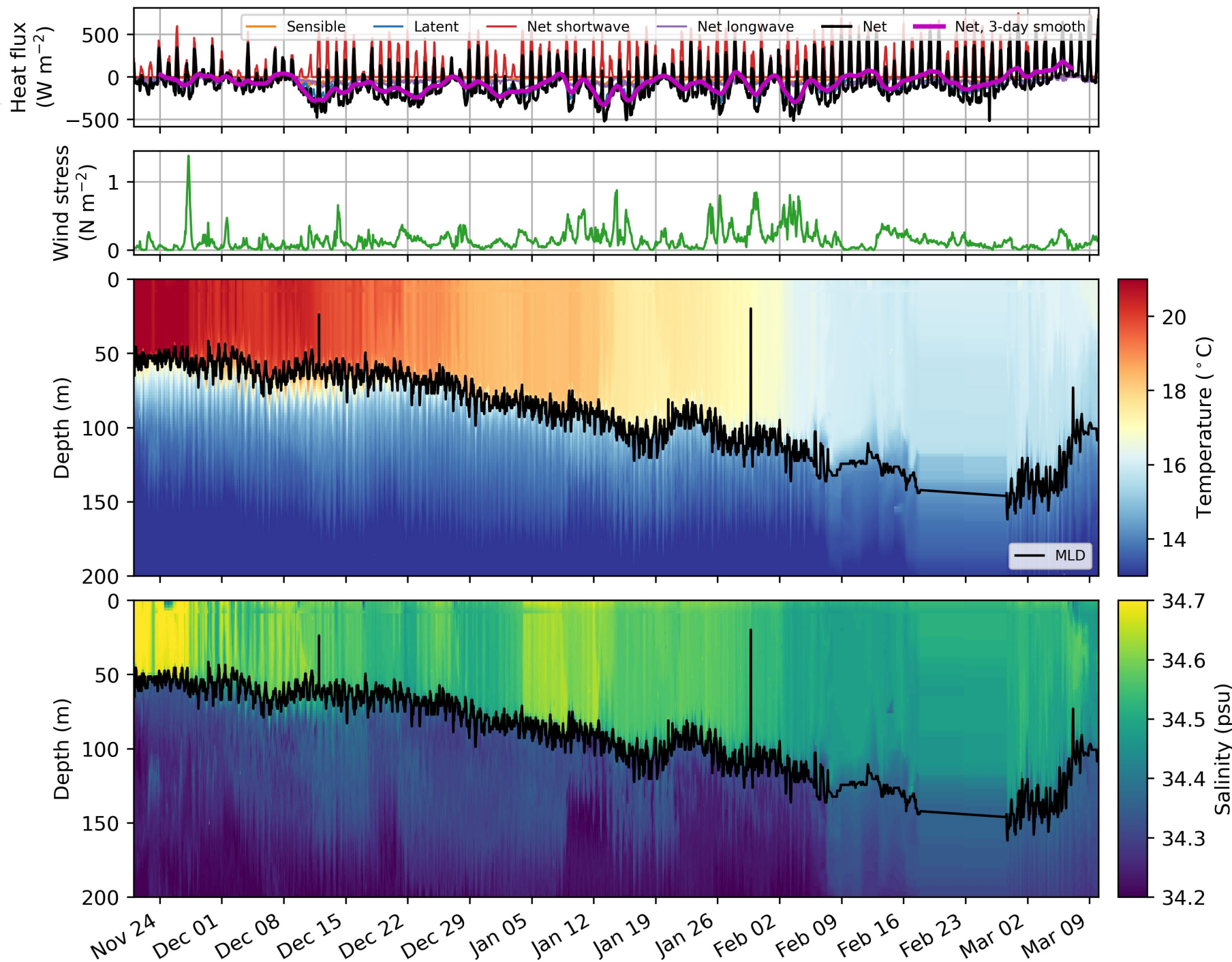
- Cold, dry air events, strong winds, and evaporation all occur, but not necessarily at the same time
- SST drops during these events

How much of this cooling is direct heat loss to the atmosphere, and how much is from vertical mixing of cooler water from below?

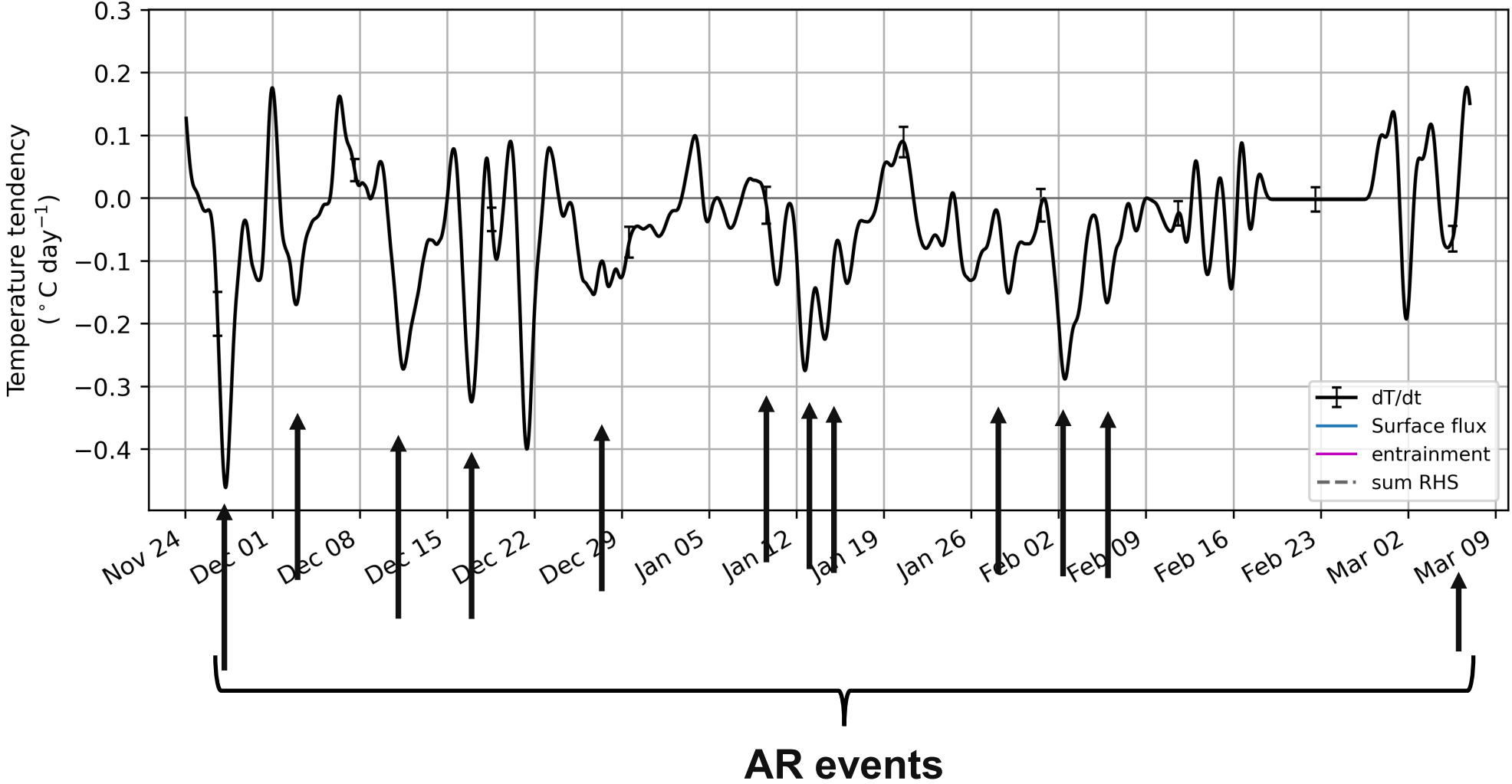


# What depletes the warm water?

- Cooling occurs during AR events
- How much is direct heat loss?
- How much is mechanical mixing?
- Wirewalker profiles resolve the evolving upper-ocean structure



# Rate of change of mixed-layer temperature



# Surface layer budgets

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$$\rho c_p \left( \frac{\partial T}{\partial t} + \mathbf{u} \cdot \nabla T \right) = \frac{\partial Q}{\partial z}$$

$$\nabla \cdot \mathbf{u} = 0$$

Define:

$$T_a = \frac{1}{h} \int_{-h}^0 T dz, \quad T(z) = \hat{T}(z) + T_a$$

Variable-depth control volume (follows from above eqns):

$$\frac{\partial T_a}{\partial t} + \mathbf{u}_a \cdot \nabla T_a + \frac{1}{h} \nabla \cdot \int_{-h}^0 \hat{\mathbf{u}} \hat{T} dz + \frac{T_a - T_{-h}}{h} \left( \frac{\partial h}{\partial t} + \mathbf{u}_{-h} \cdot \nabla h + w_{-h} \right) = \frac{Q_o - Q_{-h}}{\rho c_p h}$$

Moisan and Niiler (1998) is an excellent reference for this derivation

# Surface layer budgets

$$\frac{\partial T_a}{\partial t} + \mathbf{u}_a \cdot \nabla T_a + \frac{1}{h} \nabla \cdot \int_{-h}^0 \hat{\mathbf{u}} \hat{T} dz + \frac{T_a - T_{-h}}{h} \left( \frac{\partial h}{\partial t} + \mathbf{u}_{-h} \cdot \nabla h + w_{-h} \right) = \frac{Q_o - Q_{-h}}{\rho c_p h}$$

Evolution of  $T_a$

Advection of  
depth-avg  $T$  by  
depth-avg  
velocity

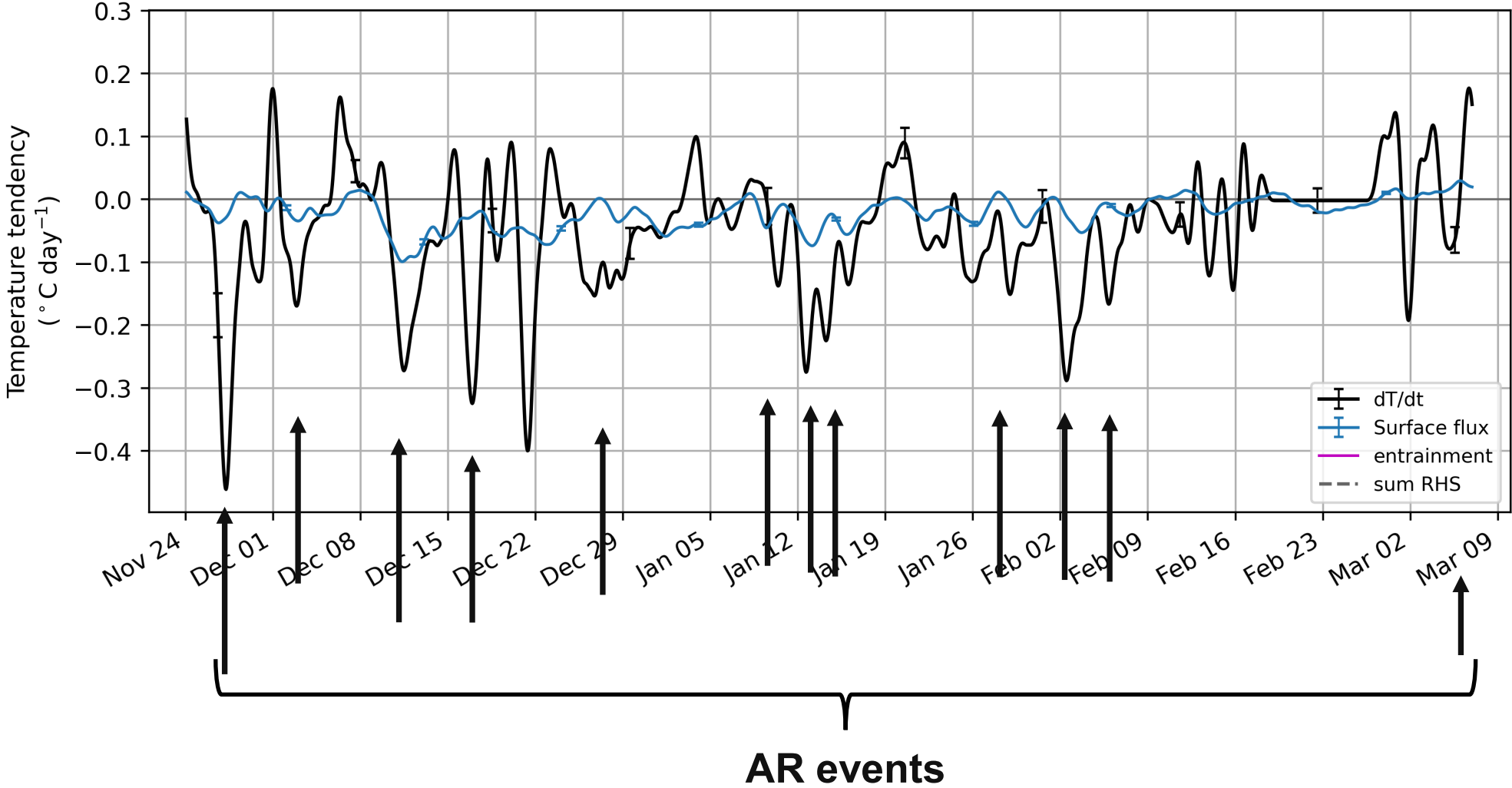
“Sheared-  
stratified  
advection”

“Entrainment”

Turbulent/radiative  
flux at top/bottom

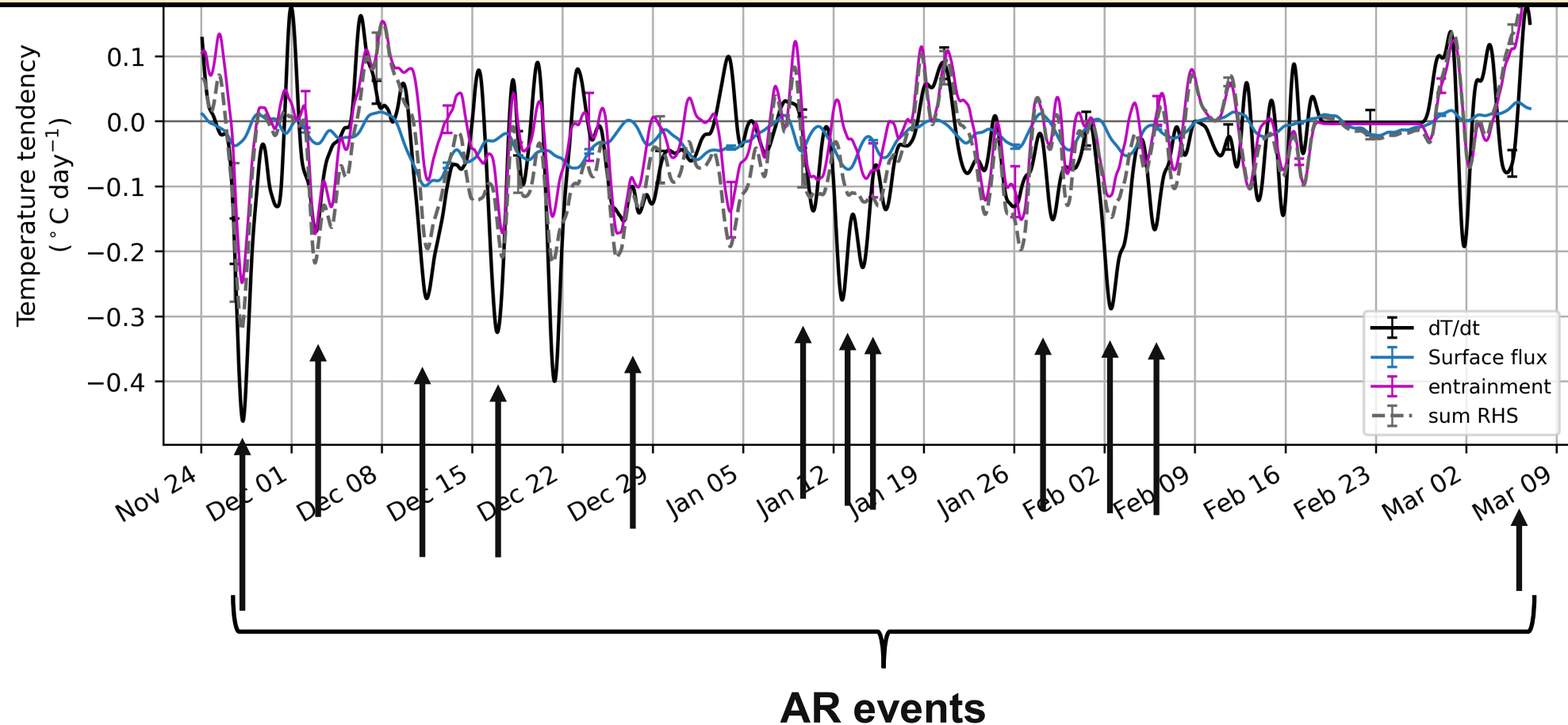
Moisan and Niiler (1998) is an excellent reference for this derivation

# Upper-layer temperature balance during AR season



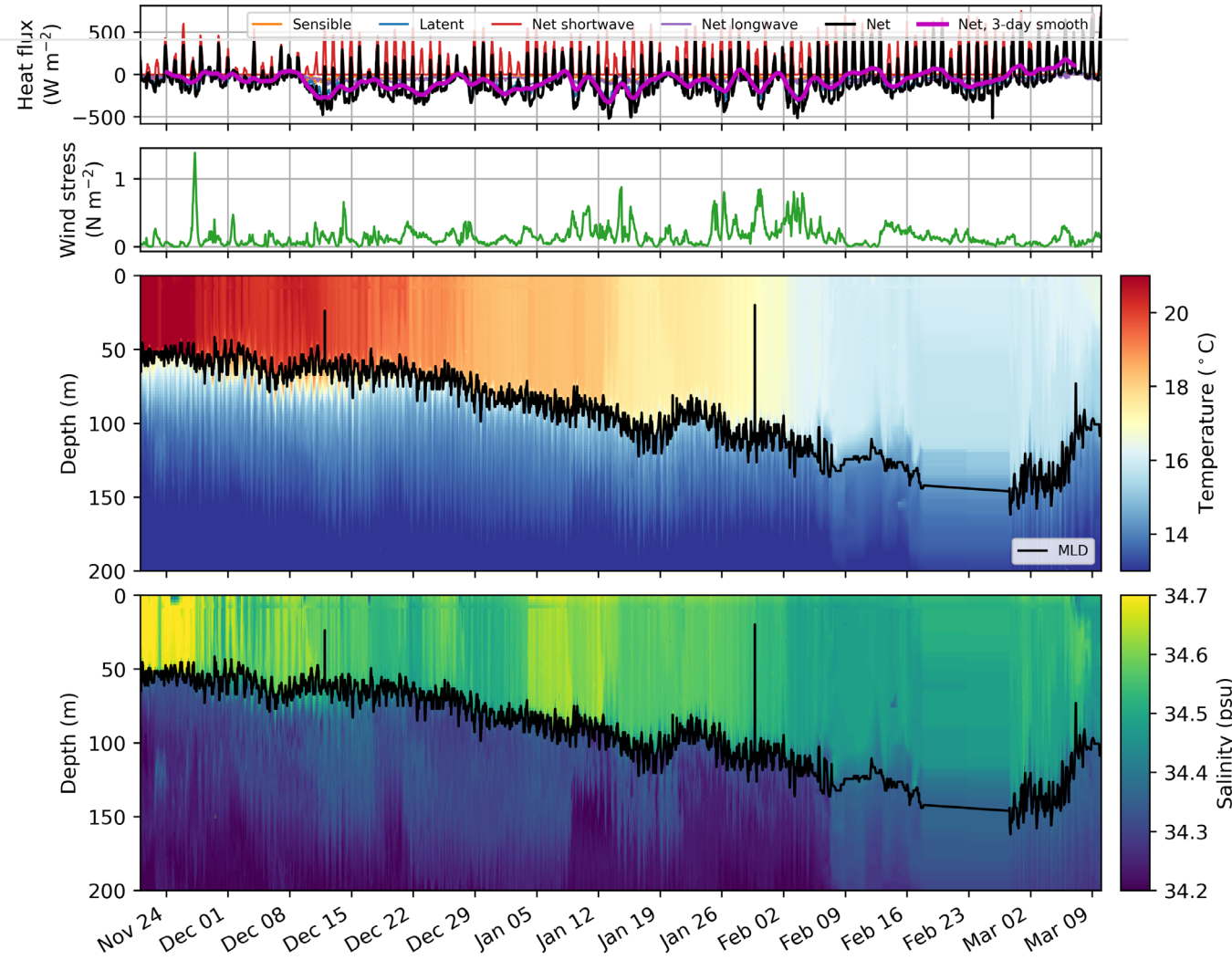
# Upper-layer temperature balance during AR season

- Wintertime cooling occurs as a sequence of events loosely associated with ARs (and probably other winter storms)
- Surface heat loss and entrainment both contribute to upper-ocean cooling
- Recovered velocity and turbulence data will allow better quantification of mixing and horizontal advection



# Conclusions

- ARs at the SAFARI site produce strong cooling of SST
- Evaporation is large, but entrainment and mixing are important to SST cooling
- Recovery of the mooring should provide currents, vertical shear, and turbulence measurements for better evaluation of entrainment, mixing, and horizontal advection
- The data are publicly available from the CW3 web page ([https://cw3e.ucsd.edu/arrecon\\_data/](https://cw3e.ucsd.edu/arrecon_data/))





**Back-up slides**

# Broad view of the AR season

- Repeated multi-day high-evaporation periods
- Strong winds, precipitation, humidity, SST, and air temperature vary together

